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Cradle-to-Grave Life-Cycle Assessment of Wooden Pallet Production in the United States

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Abstract

This study performed an environmental sustainability assessment of the wooden pallet industry in the United States using life-cycle assessment methodology. The scope of this study covered the cradle-to-grave life-cycle stages of the wooden pallet supply chain including sourcing of raw material, product manufacturing, transportation, and re-use, repair, and final disposal of pallets. The product stage was composed of raw material supply Module [A1], raw material transport Module [A2], and pallet manufacturing Module [A3]. The use and repair stage was composed of use Module [B1] and repair–reuse Module [B2]. The end-of-life was composed of Module [C]. Beneficially used coproducts and end-of-life material Module [D], which was beyond the system boundary, reported additional benefits. The average cradle-to-grave global warming (GW) impact for a functional unit (FU) of 100,000 lb (45.4 metric tons) of pallet loads of product delivered using wooden pallets was about 10.4 kg CO_2e. For the product life-cycle stage, the contribution analysis showed that the raw material supply Module [A1] and manufacturing Module [A3] had the highest values for most of the impact categories. The manufacturing Module [A3] had about 35% contribution to greenhouse gas (GHG) emissions, followed by raw material supply Module [A1] with about 34% contribution. For Module [A1], most GHG emissions came from the sawing and kiln-drying processes for production of the lumber used to make pallet parts. At Module [A3], most GW impact came from the assembly process (specifically, the fasteners), followed by the wood preparation and board shaping processes. Nonrenewable fossil fuels comprised almost 52% of total primary energy consumption of the total 225 MJ/FU. Wooden pallets showed notable GHG benefits when potential environmental benefits were considered (Module [D]), such as when wood coproducts and waste wood generated at the end-of-life stage were used as an energy source to replace natural gas at boilers.

Keywords: life-cycle assessment, wooden pallet, environmental product declarations, product category rules, LCA, EPD, PCR

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Cradle-to-Grave Life-Cycle Assessment of Wooden Pallet Production in the United States

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Executive Summary

Study Goals

The primary goal of this study was to quantify the environmental impacts of the wooden pallet manufacturing and recycling industry in the United States. For this purpose, an industry-average cradle-to-grave life-cycle inventory (LCI) was developed and a cradle-to-grave life-cycle impact assessment (LCIA) was performed for the year 2018. Life-cycle assessment (LCA) is a cradle-to-gate or cradle-to-grave analysis tool that can estimate environmental impacts associated with every stage of a product's life from raw material extraction through materials processing, product manufacturing, distribution, use, and end-of-life. This LCA study was completed in accordance with the UL Environment product category rule (PCR) for wooden pallets and International Organization for Standardization (ISO) 14040 and 14044 standards.

Method

The scope of this LCA covered the life-cycle stages of wooden pallet manufacturing starting from forest resource activities through end-of-life. This study represents wooden pallet primary manufacturing in the United States including analyses of wooden pallets with different feedstock material (i.e., softwood and hardwood) and focusing on multi-use pallets because these products represent the wooden pallet markets in the United States. The four wooden pallet types selected represent the wide range of designs used in the wooden pallet supply chain in the United States: the stringer light duty (LD), stringer heavy duty (HD), block LD, and block HD pallets. The selected design was the 48- by 40-in. (190- by 160-mm) pallet that is typically used in the distribution of fast-moving consumer and retail goods. These pallets are referred to a "distribution" or "retail" style. This is industry terminology that refers to a pallet that has the 48- by 40-in. footprint and a typical arrangement of deckboards. This pallet is used heavily in the retail industry. Historically, these types of pallets have been referred to as Grocery Manufacturers Association (GMA) pallets but are now called retail- or distribution-style pallets. The analysis was performed using weighted average industrial data collected from the wooden pallet manufacturers in the United States.

The functional unit (FU) was selected as 100,000 lb (45.4 metric tons) of pallet loads of product delivered using wooden pallets, in line with the wooden pallet PCR. This FU most aptly represents the task performed by a pallet as opposed to past ones, which were based on only trip numbers or pallets produced. Previous studies did not consider the load carrying capacity of the pallets analyzed. In this study, the load carrying capacity in the racked across the length (RAL) basis was used to take into account how the pallet was transported and stored. The number of pallets required to fulfill the selected FU was calculated using the load carrying capacity and reference service life of the pallet analyzed.

Life-Cycle Inventory

Cradle-to-grave LCI flows for manufacturing wooden pallets consists of three life-cycle stages, (1) product stage, (2) use and repair, and (3) end-of-life. Life-cycle stages consist of information modules. Product stage was composed of raw material supply Module [A1], raw material transport Module [A2], and pallet manufacturing Module [A3]; use and repair stage was composed of use Module [B1] and repair–reuse Module [B2]; and end-of-life was composed of Module [C]. Module [D], which was beyond the system boundary, reported additional benefits of wood leaving the system boundary including coproducts from unit processes leaving the system at the production stage and grinding the wood material from unusable pallets and pallet boards for energy. Using mass allocation, the unit process modeling approach was followed for conducting the LCA using SimaPro LCA modeling software. Raw material supply Module [A1] was the most energy-intensive process. When lower heating values were used, the total cumulative primary energy consumption for cradle-to-grave production of wooden pallets was 225 MJ/FU. Most energy came from fossil resources (52%), a small portion of energy needs came from nuclear (7%), and the remaining 41% came from renewable resources.

Table 1—Cradle-to-grave (Modules A1-C) and Module D life-cycle impact assessment results for 100,000 lb (45.4 metric tons) of pallet loads of product delivered

	Units	Total (Modules A1-C)	Credits and burdens beyond the system boundary (Module D)
Impact category			
Global warming	kg CO_2e	10.39	–11.48
Acidification	kg CFC11e	6.30E–02	–8.60E–03
Eutrophication	kg SO_2e	2.13E–02	–3.97E–04
Smog creation	kg Ne	1.46E+00	–1.55E–01
Ozone depletion	kg O_3e	2.66E–07	2.37E–08
Fossil fuel depletion	MJ surplus	14.36	–26.64
Primary energy consumption			
Total	MJ, NCV[a]	224.50	—
Renewable primary energy	MJ, NCV	2.61	—
Renewable primary energy biomass	MJ, NCV	89.59	—
Nonrenewable primary energy (fossil)	MJ, NCV	117.26	—
Nonrenewable primary energy (nuclear)	MJ, NCV	15.04	—

[a]NCV, net calorific value.

Life-Cycle Impact Assessment

The following six impact categories were examined using the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) v2.1: global warming (GW (kg CO_2-eq)), acidification (kg SO_2-eq), eutrophication (kg N-eq), ozone depletion (kg chlorofluorocarbons-11-eq), photochemical smog (kg NO_x-eq), and fossil fuel depletion (MJ surplus). The LCI also provided additional information such as the use of primary energy resources consumption [energy consumption from nonrenewable, renewable (wind, hydro, solar, and geothermal), and nuclear fuels, renewable and nonrenewable resource consumption], water use, and indicators describing waste.

Key Findings

The cradle-to-grave industry-average impact assessment for the entire life cycle identified where the environmental "hotspots" were found. For GW impacts, the total was 10.4 kg CO_2e per FU with manufacturing stage contributing the highest impact at 3.6 kg CO_2e per FU followed by the raw material supplies [A1] (Table 1). Most of the greenhouse gases (GHGs) were derived from the sawing and (kiln) drying processes, which are part of the raw material supply Module [A1]. When accounted for, Module [D] with a value of –11.5 kg CO_2e per FU offset the cradle-to-grave GHG emissions. Nonrenewable fossil fuels comprised almost 52% of total primary energy consumption of the total 225 MJ/FU.

Sensitivity Analysis

A sensitivity analysis was completed per the ISO standards to model the effects. The selected parameters included the electricity input, amount of fasteners used, and amount of wood material input to the wooden pallet manufacturing system Module [A3]. Overall, the variations in the environmental impacts were from a 20% increase or decrease in electricity, amount of fasteners used, or amount of wood material input used to produce wooden pallets. The increase in wood material input had the greatest effect on the GW results, whereas a 20% increase in the other two parameters resulted in about a 2% to 3% change in the GW results.

Interpretation

This study presents a comprehensive industry-average environmental impact analysis of the wooden pallet manufacturing and recycling sector in the United States. The data were collected from wooden pallet facilities throughout the United States. The industry-average LCI developed was representative of the United States for an average wooden pallet produced. The scope and content of this report was in line with the wooden pallet PCR, which will be used to develop an industry-average environmental product declaration.

Raw material supply Module [A1] and manufacturing Module [A3] were the major contributors to the overall environmental impact. The raw material supply phase, which includes lumber production, constituted about 34% of the GHG emissions. Wooden pallets showed notable GHG benefits when potential environmental benefits were considered (Module [D]), such as wood coproducts and waste wood generated at the end-of-life stage being used as an energy source to replace natural gas at boilers.

The information provided by the contribution analysis allowed us to identify which life-cycle stage had the highest

contribution to the selected environmental indicators. The contribution analysis showed that the raw material supply stage Module [A1] was the major contributor to most of the impact categories.

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Participation

This report was created in collaboration with members and staff of the National Wooden Pallet & Container Association (NWPCA). NWPCA has created a special task group to work on and provide industry guidance where needed on the development of a life-cycle assessment methodology and environmental product declaration for a wooden pallet. The members of the task group are as follows:

Brad Gething, PhD, NWCPA Director of Science & Technology Integration

LeRoi Cochran, Chair of NWPCA Science & Technology Advisory Council, Vice President of Supply Chain for 48forty Solutions

Robert Wenner, Chair of the Pallet Foundation, Member of NWPCA Industry Marketing Committee, President of Pallet Service Corporation

Jordan Piland, Chair of NWPCA Standards Committee, Vice Chair of the Pallet Foundation, Vice President of Atlas Pallets

Frank Shean, Former Chair of NWPCA Industry Marketing Committee, Member of the Pallet Foundation, President of Valley Pallets

Hinton Howell, Member of NWPCA Science & Technology Advisory Council, Vice President of Cottondale Wood Products

Ian Carter, Member of NWPCA Standards Committee, President of Crane Point Industrial, LLC

John Conway, Member of NWPCA Science & Technology Advisory Council, Member of NWPCA Standards Committee, President of Conway Robison, LLC

Keith Geiges, Member of NWPCA Science & Technology Advisory Council, Co-President of Treen Box and Pallet

Lloyd Harper, Member of NWPCA Science & Technology Advisory Council, Salesman for First Alliance Logistics Management

Ralph Rupert, Member of NWPCA Science & Technology Advisory Council, Member of NWPCA Standards Committee, Manager of Unit Load Technology for Millwood Inc.

Rob Anderson, Member of Nature's Packaging Committee, President of St. Boniface Pallet Company

Scott Geffros, Assistant General Manager at the Canadian Wooden Pallet & Container Association

Definitions (UL Environment 2019a)

Load Carrying Capacity: The amount of weight that a pallet is capable of supporting for given performance criteria (MHI 2019). Three capacity types exist: rackable, static, and dynamic load carrying.

Reuse: Recycled pallet (without repairs), pallet that is reusable without any repairs.

Repairing (reconditioning): Recycled pallet (with repairs), pallet made usable by repairing, sorting, rebuilding pallet, using new components or reclaimed components from damaged pallets.

Remanufactured (reassembled) pallet: Pallet made entirely of recycled components or parts from damaged pallets (MHI 2019).

Reference Service Life (RSL): Service life of a product which is known to be expected under a particular set, i.e., a reference set, of in-use conditions and which may form the basis of estimating the service life under other in-use conditions. The RSL of a pallet is based on several types of tests to ensure the safety and durability of the product.

Racked Across the Length: Shows the pallet is supported only at its ends, either in a rack system or conveyor.

1 Introduction

Packaging is an important component of the complex global supply chain of many products. Currently, in the United States, more than 1.8 billion pallets are in service and are used for transportation of a variety of goods each day (NWPCA 2020). About 90% of these pallets are made from wood. This trend is expected to increase 1.9% annually (NWPCA 2016; PR Newswire 2015; Freedonia Group 2015, 2020). According to Gerber and others (2020), more than 513 million new wooden pallets were produced in 2016. Increasing public awareness of environmental issues has led to demand for better environmental performance from products in conjunction with maintaining the best cost option for consumers. It is critical for manufacturers to document their environmental performance to satisfy customer demand for environmentally sound and low impact products (Bergman and Taylor 2011, Ritter and others 2011). To achieve this, a comprehensive environmental assessment of U.S. wooden pallet production is required. This LCA study was completed in accordance with the UL Environment product category rule (PCR) for wooden pallets (UL Environment 2019a) and ISO standards 14040 and 14044 (ISO 2006a, 2006b).

1.1 Study Goals and Applications

1.1.1 Goals of the Study

The key goal of this study was to quantify the environmental impacts of the wooden pallet primary manufacturing and recycling in the United States. For this purpose, an industry-average cradle-to-grave LCI was developed and a cradle-to-grave LCIA was performed for the year 2018.

1.1.2 Intended Uses

The expected outcomes included an environmental performance assessment of the current state of U.S. wooden pallet manufacturing for domestic and international consumption using up-to-date data. The outputs can be used for identification of environmental hotspots and areas of improvement in the wooden pallet sector that would further enhance existing efforts toward sustainable manufacturing and help create value for customers. This study can be used by pallet manufacturers to benchmark comparisons of environmental performance. Using the LCA developed in this project, a wooden pallet environmental product declaration (EPD) will be created by the NWPCA for a generalized pallet. This wooden pallet EPD will provide independently verified, comparable, and objective information on environmental performance of wooden pallet production and use in the United States (ISO 2006c).

1.1.3 Intended Audience

The findings will be useful to wood product manufacturers, LCA researchers, policy makers, and consumers concerned with the environmental aspects and the sustainability of the product. This work can support industry members and decision makers that seek opportunities to enhance environmental sustainability of pallet operations, use, and disposal. Also, wooden pallet EPDs that provide transparent, verified, and comparable data based on objective facts will be produced. This will allow customers to compare products based on their environmental performance under the same PCR (UL Environment 2019a, ISO 2006c). Other intended audiences include product manufacturers that use wooden pallets in their supply chain to transport goods.

1.1.4 Comparative Assertions

This LCA report does not include comparative assertions. Because future studies may perform product comparisons, this LCA study is consistent with the guidelines and principles of ISO standards 14040 and 14044 and is compliant with the wooden pallet PCR (UL Environment 2019a).

1.2 Scope of the Study

The scope of this LCA study covers the life-cycle stages of wooden pallet manufacturing starting with forest resource activities and continuing through end-of-life. This study represents wooden pallet primary manufacturing in the United States, including analyses of wooden pallets with different feedstock material (i.e., softwood and hardwood) and focusing on pallets that may be used multiple times, because these products represent the wooden pallet market in the United States (HMR 2017, 2018). The analyses were performed from cradle-to-grave including raw material supplies and transportation, product manufacturing, product transportation, re-use, recycling, recovery, and disposal of pallets (Fig. 1). The infrastructure and manufacturing, maintenance, and disposal of production equipment used in the system were not considered within the scope of this study, which was in line with the PCR. The product use phase, which includes transportation of goods using wooden pallets, is subject to high variability and uncertainty. Therefore, it was also left outside the scope of this study (UL Environment 2019a, Anil and others 2020). In compliance with the PCR, environmental impacts associated with the use phase are quantified as additional information and presented in Section 3.2. Transportation of raw materials, primary pallets, recovered pallets, and disposed pallets were accounted for.

There are two main categories of wooden pallet designs used in the United States: stringer class (Fig. 2) and block class (Fig. 3) assembly. The major functional difference between stringer and block pallets is the number of openings that accept handling equipment. Block pallets are designed to have access for full four-way entry by forklifts and pallet jacks. Alternatively, stringer pallets are designed for access on two sides. However, stringer pallets can be converted to a partial four-way entry pallet by notching the stringers.

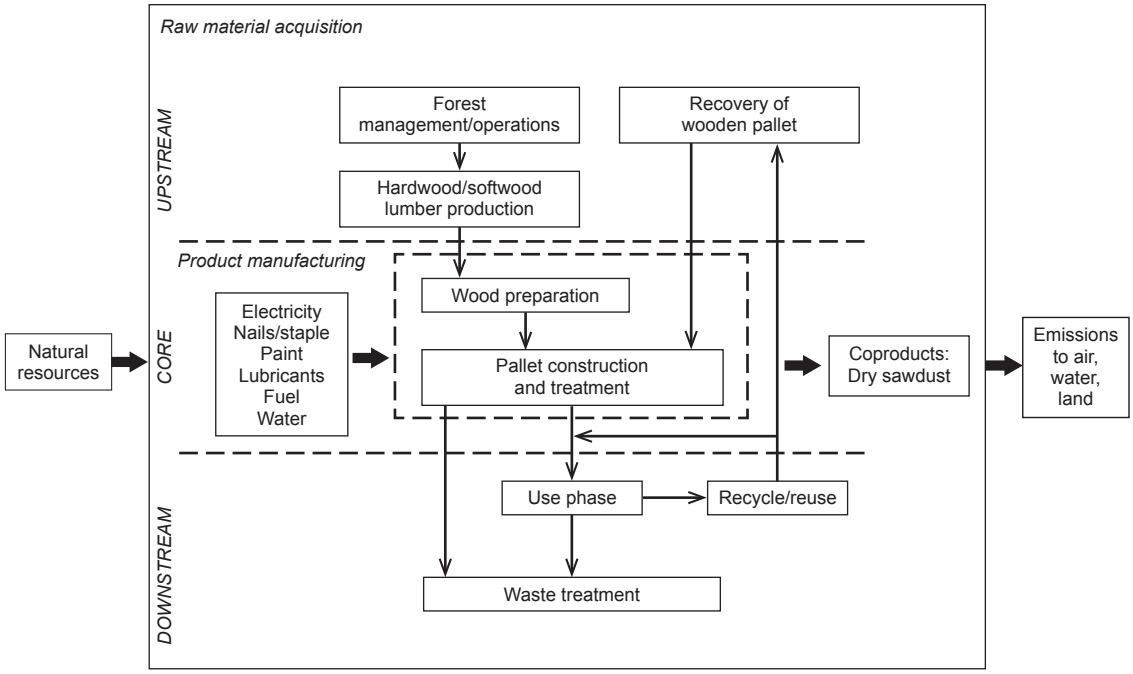

Figure 1. Life-cycle of generic wooden pallet production in the United States.

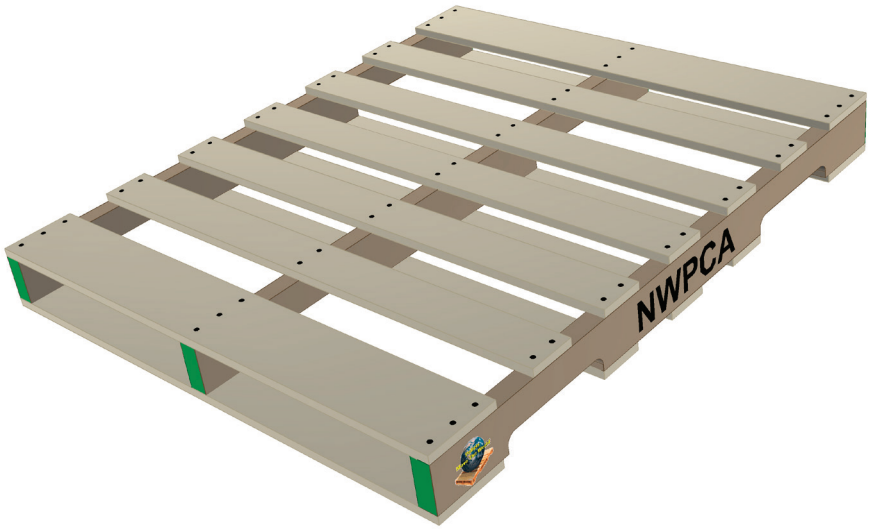

Figure 2. Schematic diagram of a stringer pallet (notched).

1.2.1 Representativeness of the Facility Data

In 2016, total estimated wood pallet production was about 513 million new pallets and 326 million repaired or remanufactured pallets (Gerber 2018, Gerber and others 2020). Two different surveys were sent to NWPCA facilities. One was to collect data for new pallet manufacturing. The second survey was sent to repaired–remanufactured pallet producers to model the pallet repair phase. Participating facilities are distributed across the United States and represent overall production from new-pallet and repair–remanufacturing facilities. For data collection from new-pallet facilities, the greatest contribution was from the southern United States with 18 respondents, followed by the northeastern United States with 10 facilities responding. Nine facilities in the Midwest responded, and three in the western United States responded. The pallet manufacturing inventory was developed based on primary (foreground) data collected from 40 new-pallet manufacturing facilities and more than 35 repair–remanufacturing facilities. Annual pallet production of the participating facilities was about 49,790,000 for new pallet production and 37,950,000 for repaired–remanufactured pallets, which was about 10% and 12% of the total production in 2018, respectively.

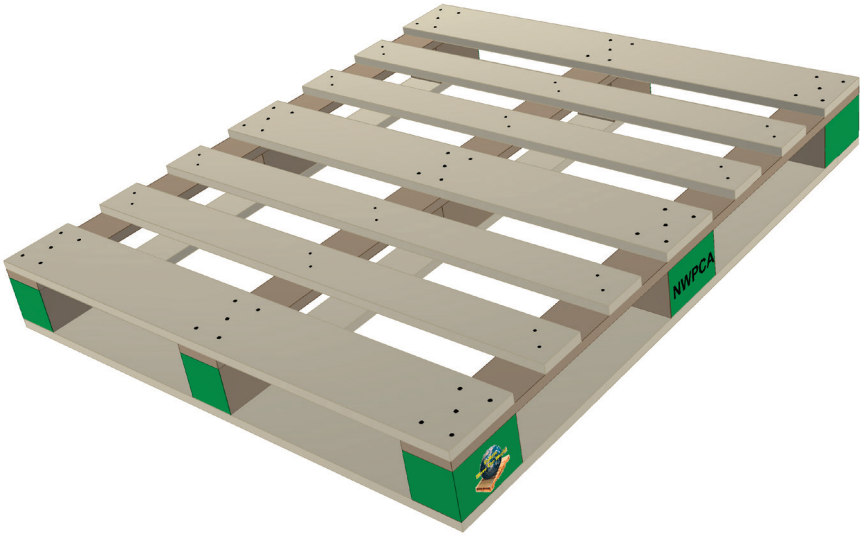

Figure 3. Schematic diagram of a block pallet.

1.2.2 System Boundary

This project considered the cradle-to-grave system boundary analyzing the whole life cycle of a wooden pallet from resource extraction (cradle) to disposal (grave). The wood flow of a generic wooden pallet is presented in Figure 4. The system boundary showing the wood flow was established to represent current production in the United States to cover different manufacturing processes. The system boundary begins with forest regeneration and ends at the end-of-life stage of a wooden pallet. Wooden pallets are generally manufactured from either hardwood (HW) or softwood (SW) rough sawn lumber and precut lumber. The common species used in pallet manufacturing in the United States are listed in Appendix A. The raw material acquisition stage includes site preparation and planting seedlings, forest management including fertilization and thinning, harvesting, transportation of saw logs to the lumber manufacturing facility, and lumber production itself. Lumber production includes mainly production of rough sawn SW and HW lumber from incoming saw logs with some kiln-drying of SW lumber. In addition to HW and SW lumber use, a small amount of plywood and oriented strandboard (OSB) were reported by some facilities.

A variety of wooden pallets are produced in the United States differing in their size, design, and function. The pallet manufacturing phase covers common processes of pallet production, i.e., wood preparation and board shaping (cutting of lumber to appropriate size and notching), assembly, heat treatment, painting, and stamping at the pallet manufacturing facility. Cutting of lumber to size may be performed at the lumber manufacturing facility, yet it is considered in the pallet manufacturing system boundary. Depending on the desired use of the product, some additional processes may be included in the system boundary such as heat treatment or stamping. Heat treatment or chemical treatment may be used to comply with International Standards for Phytosanitary Measures No. 15 (ISPM 15) (FAO 2009) if pallets are used for international consumption or by customer request.

Use of wood in pallet manufacturing has environmental benefits because it is a renewable material, i.e., it may be recycled or reused. After the use phase and an inspection, some pallets are reused by consumer product manufacturers. Although roughly 13% of the pallets produced in 2016 were received by solid waste disposal facilities, only about 5% of these pallets were eventually landfilled because of diversion practices such as grinding for use as mulch or fuel (Shiner 2018, Gerber 2018, Gerber and others 2020). The other 87% were received by the repairing–remanufacturing facilities. At the repairing–remanufacturing facilities, about 53% of the recovered pallets were repaired and about 12% were reused without repair. This number was lower in Park and others (2017), who reported 84% of damaged stringer (GMA-style) pallets received were repaired for reuse excluding pallets reused as is. Block pallets were not considered by Park and others (2017), which would probably affect this 84% value. Pallets are repaired through the refastening of connections or replacement of damaged pallet components. Sometimes, pallets are dismantled and used for repairs and remanufacturing. About 31% that could not be reused or repaired were dismantled for reuse in reconditioned pallets or ground for other uses. The rest of the pallets, about 4%, were ground and used for other purposes. Wood from dismantled pallets displaced the virgin material coming into the pallet manufacturing supply chain. This displacement offset the environmental burden resulting from producing lumber along with forest management and harvesting operations by extending the service life of the pallet and pallet parts. The rest of the wood material that could not be used in repairs were ground and used for applications such as fuel, mulch, or animal bedding.

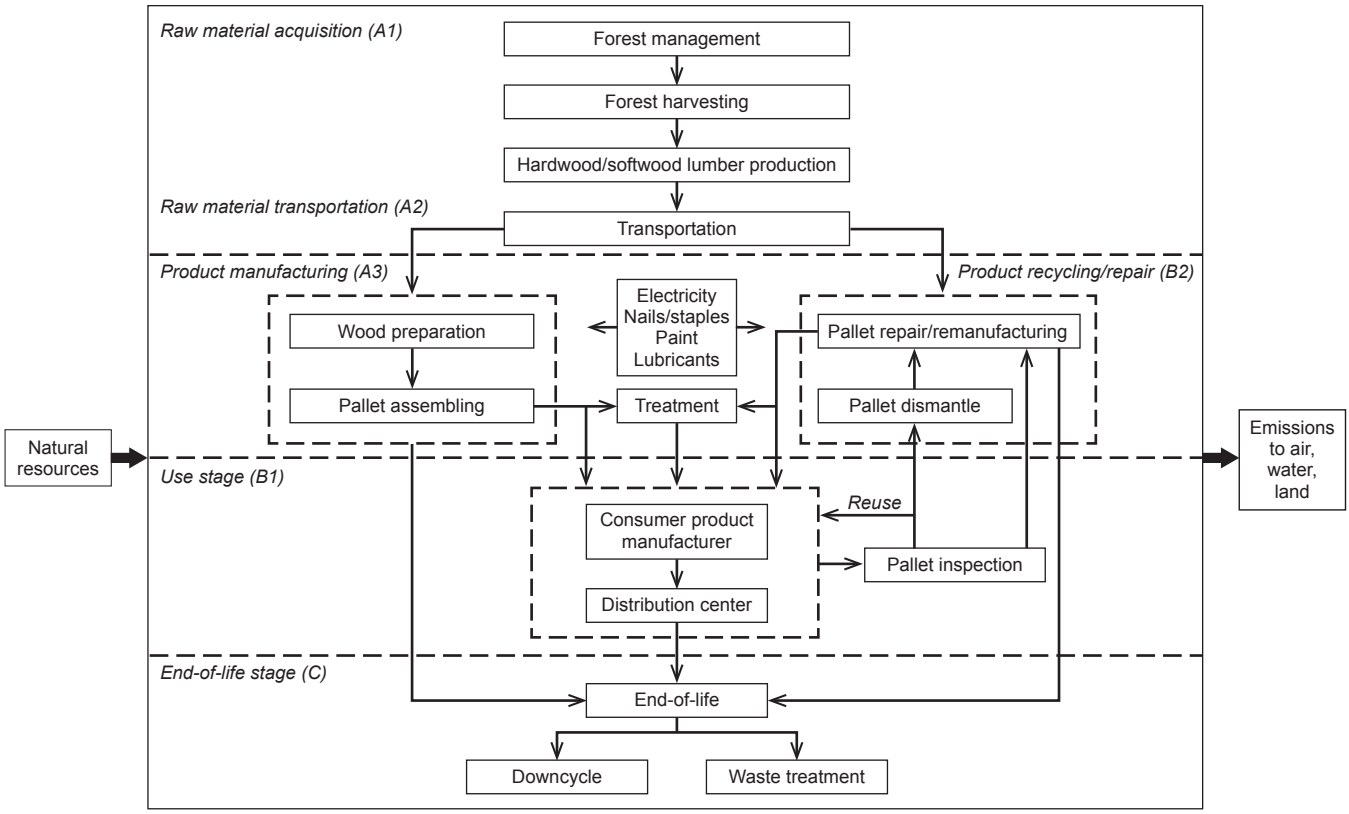

Figure 4. Solid wooden pallet process wood flow diagram.

The environmental burdens resulting from transportation of raw materials to a pallet production facility, the reuse, recovery, and recycling manufacturing operations, and product disposal were considered in this study.

1.2.3 Cut-Off Rules

In accordance with the wood pallet PCR, a process or activity that contributes less than 1% of the total mass or energy may be omitted from the inventory. In this study, no cut-offs were used in the analysis.

1.3 Functional Unit

The FU is a measure of the function of the service or product generated by the studied system. It is used to normalize the material inputs and outputs and environmental impacts of the system based on the function of the product. The FU was selected as 100,000 lb (45.4 metric tons) of pallet loads of product delivered using wooden pallets, in line with the PCR. The number of pallets required to fulfill the selected FU was calculated using the load carrying capacity and reference service life (RSL) of the pallet analyzed:

$$\text{Number of pallets required} = \frac{100{,}000\,\text{lb (45.4 metric tons) of product delivered}}{\text{RSL}\left(\text{number of}\,\frac{\text{trips}}{\text{pallet}}\right)\times\text{load bearing capacity}\left(\frac{\text{lb}}{\text{trip}}\right)} \quad (1)$$

The RSL is the estimated number of trips a wooden pallet can make until the end-of-life phase. The pallet design, use phase, and handling and loading conditions have a significant impact on pallet durability and trip numbers. In this study, the FasTrack test protocol (developed and used at the Center for Unit Load Design of Virginia Tech University, Blacksburg, Virginia, USA) was used to quantify average number of trips up to the first repair (component replacement) using 30 replicate tests for each pallet type investigated (Cao 1993; ASTM 1998, 2017; VT 2018, 2019). The Pallet Design System (PDS) (NWPCA, Alexandria, Virginia, USA) methodology was used to identify the number of trips a pallet can make after the first repair or component replacement (NWPCA 2019). It was assumed that the pallet was repaired only once. The number of replacements can be determined by the PDS protocol as outlined in the guidance provided in the PCR, Section 3.1.1. However, as a prediction tool, PDS is generally understood to be a conservative estimate of pallet durability but is currently the only available source for reliable durability estimation. See Appendix B for design details and pallet dimensions.

Wooden pallets are produced in various designs differing in size and dimensions of pallet components. For industry-average LCA analysis, the four most commonly used wooden pallet types were selected representing the wooden pallet supply chain in the United States (NWPCA 2014,

Table 2—Specifications, predicted reference service life (RSL), and functional units of wooden pallet designs

Pallet type	Overall predicted service life (trips)	Load capacity[a] (racked "across the length") (lb)[b]	Average board feet per pallet	Average weight (lb)	Number of pallets required to transport 100,000 lb of product
Stringer light duty	10	1,000 (454)	10.9	31	10
Stringer heavy duty	38	1,500 (680)	14.4	41	1.75
Block light duty	16	1,500 (680)	14.2	44	4.07
Block heavy duty	66	2,500 (1,134)	22.1	67	0.61

[a]The Pallet Design System (National Wooden Pallet and Container Association, Alexandria, Virginia, USA) incorporates a safety factor of 2 to 2.5 in all loading capacity estimations.
[b]Equivalent values in kilograms are given in parentheses.

Brindley 2006). The selected, most typical, designs were 48 by 40 in. (19 by 16 cm) retail- or distribution-style stringer LD, stringer HD, block LD, and block HD pallets (see Appendix B for technical specifications). The design specifications and RSL data for the four different pallet types and FUs are provided in Table 2. Load carrying capacity and RSL of the pallets were used to calculate the amount of pallets required to satisfy the selected FU (Table 2).

As noted, the load carrying capacity is vitally important in determining the FU of a pallet. The load carrying capacity of a pallet can vary greatly depending on the intended usage and should therefore be clearly stipulated. For this study, the RAL basis was used for loading capacity values, because it is typically the most aggressive support condition a pallet may encounter. As expected, HD pallets lasted longer and were heavier than LD pallets for both stringer and block.

The design specifications and FU for the industry-average pallet used for the analysis are provided in Table 3.

1.4 Allocation Rules

Allocation is required for multi-output systems where two or more functions are delivered (ISO 2006b). For the life-cycle phases including multifunctional processes, economic allocation can be used depending on the value of product and coproducts. However, for this study, mass allocation was used (UL Environment 2019a). Mass allocation has become the preferred approach for wood products given the uncertainty and poor availability of pricing data especially for coproducts (Taylor and others 2017, UL Environment 2019b). The system process was divided into unit processes, and allocation occurred at the wood preparation and board shaping unit processes. Producing pallet boards from cants and lumber coming in produces wood coproducts. The energy and material inputs of the downstream unit processes, including assembly–nailing, heat treatment, and stamping–painting, were not allocated to coproducts because they were consumed after the coproducts were produced.

Table 3—Specifications and functional units of the industry-average wooden pallet

Specification	Value
Average weight (kg) at 12% moisture content	18.57
Average weight (oven-dry kg) at 12% moisture content	16.58
Average actual board feet per pallet	14.069
Load supported during the life of the pallet (racked "across the length") (lb)	46,986
Number of pallets required to transport 100,000 lb (45.4 metric tons) pallet loads of product	2.13

1.5 Life-Cycle Impact Assessment Methodology and Types of Impacts

The impact categories examined in this study included GW (kg CO_2-eq), acidification (kg SO_2-eq), eutrophication (kg N-eq), ozone depletion (OD) (kg chlorofluorocarbons-11-eq), smog formation (kg O_3-eq), and fossil fuel depletion (FD) (MJ surplus).

Among the available methods for the LCIA, TRACI v2.1 was used in this study (Bare 2011). TRACI is a midpoint level impact assessment model developed by the U.S. Environmental Protection Agency and is specifically representative for the United States using input parameters consistent with U.S. conditions.

The LCIA phase establishes links between the LCI results and potential environmental impacts. The LCIA calculates impact indicators, such as GW and smog. These impact indicators provide general, but quantifiable, indications of potential environmental impacts. The target impact indicator, the impact category, and means of characterizing the impacts are summarized in Table 4. The six impact categories reported were consistent with the requirement of the wood pallet PCR (UL Environment 2019a).

1.6 Biogenic Carbon Calculations

The carbon accounting was performed by taking into account the biogenic carbon content of wood, which is a biobased material. The calculations were performed in line with the wooden pallet PCR and conform to ISO 21930

Table 4—Selected impact indicators, characterization models, and impact categories

Impact indicator	Characterization model	Impact category
Greenhouse gas emissions	Calculate total emissions in the reference unit of CO_2 equivalents for CO_2, methane, and nitrous oxide.	Global warming
Releases to air decreasing or thinning of ozone layer	Calculate the total ozone forming chemicals in the stratosphere including CFCs,[a] HCFCs,[b] chlorine, and bromine. Ozone depletion values are measured in the reference unit of CFC equivalents.	Ozone depletion
Releases to air potentially resulting in acid rain (acidification)	Calculate total hydrogen ion (SO_2) equivalent for released sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification value of SO_2 mole equivalents is used as a reference unit.	Acidification
Releases to air potentially resulting in smog	Calculate total substances that can be photo-chemically oxidized. Smog forming potential of O_3 is used as a reference unit.	Photochemical smog
Releases to air potentially resulting in eutrophication of water bodies	Calculate total substances that contain available nitrogen or phosphorus. Eutrophication potential of N-eq is used as a reference unit.	Eutrophication
Extraction of nonrenewable primary resources (fossil) at a rate higher than the replacement rate	Calculate the quantities of natural gas, oil, and coal resource consumed at rates greater than nature replenishes them (MJ surplus).	Fossil fuel depletion

[a]CFC, chlorofluorocarbons.
[b]HCFC, hydrochlorofluorocarbons.

(ISO 2017). ISO 21930 Clause 7.2.2 suggests biogenic carbon entering the product system is considered as removal from the natural environment and is characterized as a negative emission. Biogenic carbon that leaves a system as product, and coproducts, and is emitted directly to the atmosphere when combusted was considered and accounted for as emitted CO_2. Note 2 of ISO 21930, Section 7.2.11, states that forests are considered as sustainably managed forests if the forest carbon stocks are identified as stable or increasing. Because U.S. forest stock volumes are increasing, U.S. forests are considered to be sustainability managed forests (FAO 2015, Oswalt and others 2019, Hoover and Riddle 2020).

2 Life-Cycle Inventory Analysis

The data were collected in line with the data quality requirements addressed by ISO 14044 to ensure quality and reliability. Also to ensure the reliability and accuracy of the data used in the analyses, mass and energy balances were developed from survey data. In addition, sensitivity and scenario analyses were conducted to address completeness, consistency, and uncertainty issues relevant to the data used. The methodology used, the process input and output data, and the LCI generated in this study are provided in detail to allow other LCA practitioners to reproduce the results presented in this study.

2.1 Industry-Wide Data Calculation Rules

The facilities reported the number of pallets produced in 2018. Data collected were weight-averaged using the following equation (missing data were not averaged as zeros):

$$\bar{P}_{\text{weighted}} \frac{\sum_{i=1}^{n} P_i\, x_i}{\sum_{i=1}^{n} x_i} \tag{2}$$

Where $\bar{P}$ is the weighted average of the values reported by the facilities, P_i is the reported mill value, and x_i is the fraction of the mill's value to total production for that specific value. Because the surveyed mill data varied between facilities, a statistical analysis was conducted. In this study, the weighted coefficient of variation (CoV_w) was calculated (NIST ITL 1996). The weighted coefficient of variation (CoV_w) is the weighted standard deviation (sd_w) divided by the weighted mean ($\bar{P}_{\text{weighted}}$):

$$\text{sd}_\text{w} = \sqrt{\frac{\sum_{i=1}^{N}\left(x_i - \bar{x}_w\right)^2}{\frac{\left(N'-1\right)\sum_{i=1}^{N} w_i}{N'}}} \tag{3}$$

$$\text{CoV}_\text{w} = \frac{\text{sd}_\text{w}}{\bar{P}_{\text{weighted}}} \tag{4}$$

Where w_i is the weight of the ith observation, N is the number of nonzero weights, and $\bar{x}_w$ is the weighted mean of the observations. SimaPro version 9 (PRé Consultants 2019) was used as the accounting program to track all the environmental inputs and outputs crossing the system boundary.

2.2 Primary Data Sources

Primary (foreground) data were collected using survey questionnaires sent to wooden pallet manufacturing and recycling–remanufacturing facilities in the United States. All measurable data on raw material and energy inputs, product and coproduct outputs, emissions to water, air, and land, and waste generated were collected for the unit processes included in the current wooden pallet production facilities in the United States. Material and energy flows

of the wooden pallet primary production, recycling–reuse–repair, and disposal were generated based on the operational data for core processes, the raw data, and emissions on yearly operation of the manufacturers in year 2018, which was supplied by the facilities. Site visits were also conducted at various times and locations.

2.3 Forestry Operations and Lumber Production (A1)

Primarily, HW lumber including precut and SW lumber including precut are used at wooden pallet manufacturing facilities, followed by plywood and OSB, although these are used in very small quantities. Some SW lumber was kiln-dried during lumber production depending on customer specifications. Forestry operations data including growing seedlings, regeneration, site preparation, planting, thinning, fertilization, and final harvesting were embedded in the lumber production adopted from Consortium for Research on Renewable Industrial Materials (CORRIM) reports representing U.S. operations. This stage, [A1], is also referred to as the raw material supply in this report. The LCI of SW and HW lumber production in the United States was retrieved from CORRIM reports (Milota 2015a, 2015b; Hubbard and others 2020). In addition to HW and SW lumber use, small amounts of plywood and OSB were used at some facilities, LCI data of which were adopted from CORRIM datasets (Oneil and others 2010; Puettmann and Kaestner 2016a, 2016b, 2016c). Table 5 presents the weighted-average wood material inputs used in the production of 1 m^3 of wooden pallet.

2.4 Material Transportation (A2)

The wood raw material was delivered to the pallet manufacturing facilities using rail and truck transportation. The weighted average transportation of wood raw material is presented in Table 6. The majority of the materials were delivered by truck although some of the SW lumber and plywood were delivered by rail.

2.5 Wooden Pallet Manufacturing (A3)

The raw material inputs included HW and SW lumber and included precut lumber. In addition, some facilities had limited amounts of engineered wood product inputs (plywood and OSB). The primary product output of new wood pallet manufacturing systems was wooden pallets. Coproducts included sawdust, hogged material, wood chips, scrap wood, and shavings. About 68% of the lumber used by the manufacturers was SW.

To perform the mass balance, mass of the pallet output was calculated based on the volume of wood that constitutes a pallet. Where facilities did not report the value for pallet volume, it was assumed that a generic wooden pallet in the United States constituted 15 actual board foot (bf) (0.04 m^3) of wood material (Gething 2018). This value was higher than was reported by Kočí (2019) at 12 bf (0.03 m^3) per pallet for central–eastern European block pallets. However, other studies reported that the wood content in a pallet ranged from 8.6 to 17.6 bf (0.02 to 0.04 m^3) (McKeever and others 1986, Carrano and others 2014, Park and others 2017, Kočí 2019). In the United States, it is common to report wood use in actual bf for pallet production unlike most other wood products. Manufacturers reported the information on the species used and the region the lumber was sourced from and if it was green (freshly cut) or dry. Wood flows in the gate-to-gate pallet manufacturing system were determined on an oven-dry (OD) kilogram basis. The results of the weight-averaged mass balance are provided in Table 7. The overall mass balance difference was less than 3%. A mass balance difference of less than 10% is good for wood product production, and a difference of less than 5% is excellent (Bergman and Bowe 2008).

The wooden pallet manufacturing system considered three unit processes: wood preparation and board shaping, assembly–nailing, and supplementary processes. Supplementary processes included treatment, stamping, and painting. Inputs and outputs of each process based on weighted-averaged data from new wooden pallet manufacturing facilities is provided in detail in Tables 8 and 9. Unit process flows are presented in per 100,000 lb (45.4 metric tons) of pallet loads of product delivered. (see Appendix C for LCI per pallet manufactured). Wood material (primarily lumber) entering the pallet production system was converted on a mass basis into pallets at a rate of 82% with the remaining wood out being sawdust, hogged

Table 5—Wood resources used per cubic meter wooden pallet manufactured

Wood material	Unit	Weighted average
Hardwood lumber	m^3	4.56E–01
Softwood lumber (green)	m^3	2.10E–01
Softwood lumber (dry)	m^3	4.99E–01
Plywood	m^3	9.41E–03
Oriented strandboard	m^3	7.40E–04

Table 6—Weighted-average transportation by mode for materials to wooden pallet manufacturing facility per cubic meter pallet manufactured

Material	Unit	Mode	Weighted average
Precut hardwood lumber	tkm	Truck	5.33E+01
Precut softwood lumber	tkm	Truck	1.56E+02
Hardwood lumber	tkm	Truck	6.19E+01
Softwood lumber	tkm	Truck	1.60E+02
Softwood lumber	tkm	Rail	3.14E+01
Plywood	tkm	Rail	5.66E–02
Plywood	tkm	Truck	7.99E–01
Oriented strandboard	tkm	Truck	3.75E–02

Table 7—Mass balance of new wooden pallet manufacturing

	Unit	Weighted average	Mass (%)	CoV_w (%)
Wood input				
Hardwood precut lumber	OD kg/pallet	1.68	8.0	200
Hardwood lumber	OD kg/pallet	5.04	24.0	115
Softwood precut lumber	OD kg/pallet	1.67	7.9	189
Softwood lumber	OD kg/pallet	12.45	59.2	84
Plywood	OD kg/pallet	0.15	0.7	413
Oriented strandboard	OD kg/pallet	0.02	0.1	736
Total input	OD kg/pallet	21.01		
Wood output				
Sawdust	OD kg/pallet	1.45	6.8	94
Hogged material	OD kg/pallet	0.92	4.3	155
Wood chips	OD kg/pallet	1.10	5.2	190
Scrap wood	OD kg/pallet	0.01	0.0	1,552
Shavings	OD kg/pallet	0.29	1.4	473
Pallet	OD kg/pallet	17.50	82.3	101
Total output	OD kg/pallet	21.25		

material, wood chips, scrap wood, and shavings. Electricity consumption for the precut lumber received by the facilities was accounted for in the gate-to-gate system boundary and was adopted from Bergman and Bowe (2011).

The wooden pallet boards produced were assembled using fasteners at the assembly–nailing unit process. Fasteners used in the facilities include staples, nails, bolts, and screws.

Some additional processes may be included in the manufacturing of the wooden pallet depending on the desired final product. These optional processes include heat treatment, painting, and stamping. Primarily, natural gas and propane were used as heat treatment fuel, and about 21% of the new pallets produced were heat-treated. Weighted industry-average inputs and outputs of the additional processes are provided in Table 10.

2.6 Use Stage and Pallet Repair–Remanufacturing (B1, B2)

These informational modules cover the time from when the pallet leaves the production stage [A3] until it reaches end-of-life [C]. Use stage [B1] of wooden pallets for transportation and warehousing of goods is subject to high variability and uncertainty. Therefore, in line with the PCR because no primary data were collected, it was not included in the system boundaries. Regardless, we presented GHGs from the use phase using hypothetical data in Section 3.2 Additional Environmental Information. The GW impacts resulting from the use phase were calculated assuming (1) an average of 50 km, (2) a low of 25 km, and (3) a high of 100 km.

For the repair and reuse stage [B2], Table 11 presents the gate-to-gate process flows developed for the pallet repair–remanufacturing. Transportation to the facility from the user was accounted for in the analysis. The data collected from the facilities showed that the weighted-average distance that the pallets were transported was about 65 km. Based on data reported from the repair–remanufacturing survey, a majority of the pallets were repaired (about 53%, at the facility). For the remaining 47%, about 12% were reused without repair, 31% were dismantled, and 4% were used for other purposes. About 37.3% of the boards from the dismantled pallets were recovered and used for repairs and remanufacturing. The rest of the dismantled pallets that could not be reused were ground and repurposed as mulch, fuel, or animal bedding.

2.7 End-of-Life Phase and Potential Environmental Benefits (C, D)

At the end-of-life (after the use phase), about 13% of pallets were sent to solid waste disposal facilities, where only about 5% of this total were actually landfilled because of diversion practices. For the rest of the pallets, 37.3% of them were dismantled and the remaining pallets were ground and beneficially used for mulch, animal bedding, or energy. The end-of-life analysis was performed based on the weighted average of the four pallet types (Table 12). For the recyclable material, the cut-off method was used for the impact assessment analysis. Beneficially used coproducts and end-of-life material were calculated and presented under Module [D]. Module [D] represents the potential avoided production of primary materials in the technosphere by beneficial use of material outputs from the product life cycle. In this study, beneficial use wood coproducts from Module [A3] and product disposed at [C3] were accounted for. This included the reuse of dismantled boards replacing virgin lumber coming in and wood fuel used in boilers replacing natural gas. For wood fuel used in wood boilers to replace natural gas, the boiler efficiencies were assumed

Table 8—Inputs and outputs for the wood preparation and board shaping unit process for 100,000 lb (45.4 metric tons) of pallet loads of product delivered

	Unit	Weighted average	Allocation (%)
Products/coproducts			
Wood boards, at pallet facility	p	2.13	82.3
Sawdust	OD kg	3.08	6.8
Hogged material	OD kg	1.95	4.3
Wood chips	OD kg	2.33	5.2
Scrap wood	OD kg	0.01	0.0
Shavings	OD kg	0.62	1.4
Materials/fuels			
Wood resources, average, at pallet facility	m^3	1.96E–04	
Greases	g	2.48E–01	
Motor oil	g	7.23E–01	
Hydraulic fluid	g	1.52E+00	
Lubricating fluid	g	1.00E+00	
Plastic wrapping	g	6.37E–01	
Cardboard packaging	g	4.79E–01	
Natural gas	L	2.64E+01	
Diesel	L	7.57E–02	
Gasoline	L	7.71E–04	
Liquefied petroleum gas	L	3.47E–03	
Wood fuel	OD kg	1.96E–03	
Diesel, forklift	L	2.35E–02	
Diesel, truck	L	1.03E–02	
Gasoline, truck	L	1.05E–04	
Propane, forklift	L	7.42E-02	
Electricity/heat			
Electricity	kWh	1.56E+00	
Waste			
Steel scrap	g	41.844	
Plastic wrap	g	0.980	
Cardboard packaging	g	10.648	
Hydraulic fluid	g	0.160	
Motor oil	g	0.023	
Greases	g	0.003	
Lubricants	g	2.087	

Table 9—Inputs and outputs for the pallet assembly–nailing unit process for 100,000 lb (45.4 metric tons) of pallet loads of product delivered

	Unit	Weighted average	Allocation (%)
Products/coproducts			
Wood pallet, assembled	p	2.13	100
Materials/fuels			
Wood boards, at pallet facility	p	2.13E+00	
Fasteners	g	5.58E+02	
Greases	g	2.32E–01	
Motor oil	g	6.20E–01	
Hydraulic fluid	g	2.42E+00	
Lubricating fluid	g	1.07E+00	
Plastic wrapping	g	1.46E–02	
Cardboard packaging	g	1.40E–01	
Natural gas	L	1.17E+01	
Liquefied petroleum gas	L	3.47E–03	
Diesel	L	5.82E–03	
Gasoline	L	7.10E–04	
Wood fuel	OD kg	1.96E–03	
Diesel, forklift	L	2.35E–02	
Diesel, truck	L	1.03E–02	
Gasoline, truck	L	1.05E–04	
Propane, forklift	L	7.42E–02	
Electricity/heat			
Electricity	kWh	6.96E–01	
Waste			
Cardboard packaging	g	3.549	
Hydraulic fluid	g	0.160	
Motor oil	g	0.023	
Greases	g	0.003	
Lubricants	g	2.087	

Table 10—Inputs and outputs for the treatment–stamping–painting for 100,000 lb (45.4 metric tons) of pallet loads of product delivered

	Unit	Weighted average	Allocation (%)
Products/coproducts			
Wooden pallet final, pallet facility	p	2.13	100
Materials/fuels			
Wood pallet, assembled	p	2.13E+00	
Natural gas	L	4.15E+00	
Liquefied petroleum gas	L	5.56E–02	
Fungicide	g	1.12E–01	
Paint	g	4.90E+00	
Ink	g	1.62E–03	
Electricity/heat			
Electricity	kWh	0.05	

Table 11—Gate-to-gate process inputs and outputs based on weighted-average data from pallet repair–remanufacturing facilities per pallet repaired (SimaPro inputs, mass allocation)

	Unit	Weighted average	Allocation (%)
Products/coproducts			
Pallet	p	1.00E+00	90.1
Sawdust	OD kg/pallet	2.67E–02	0.0
Hogged material	OD kg/ pallet	4.98E–01	0.5
Wood chips	OD kg/ pallet	5.62E+00	9.3
Scrap wood	OD kg/ pallet	6.11E–02	0.1
Wood fuel	OD kg/ pallet	0.00E+00	0.0
Materials/fuels			
Hardwood lumber	kg/pallet	2.31E–01	—
Softwood lumber	m^3/pallet	1.10E–04	—
Natural gas	L/pallet	9.94E+00	—
Diesel	L/pallet	9.30E–05	—
Propane	L/pallet	5.12E–03	—
Diesel, forklift and trucks	L/pallet	2.40E–04	—
Propane, forklift	L/pallet	2.62E–02	—
Truck transportation–lumber	metric tons.km/pallet	1.26E–02	—
Transportation–pallet	t.km	1.21E+00	—
Staples	g/pallet	2.54E–02	—
Nails	g/pallet	2.87E+01	—
Paint	g/pallet	1.66E–01	—
Lubricating fluid	g/pallet	1.11E+00	—
Electricity/heat			
Electricity	kWh/pallet	1.42E–01	—
Waste			
Steel scrap	g/pallet	1.77E+01	—
Plastic wrap	g/pallet	2.59E–01	—
Cardboard packaging	g/pallet	1.06E+01	—
Lubricants	g/pallet	3.69E–01	—

Table 12—End-of-life treatment stage data for 100,000 lb (45.4 metric tons) of pallet loads of product delivered

Type[a]	Percentage by mass	Unit	Value
Recovered boards	37.3	OD kg	13.18
Landfill	5.0	OD kg	1.76
Fuel	17.3	OD kg	6.11
Mulch and animal bedding	40.4	OD kg	14.25
Total	100.0	OD kg	35.30

[a]Wood material in use is 12% moisture content (wet basis), which is accounted for.

to be 80% and 74% for natural gas and wood boilers, respectively (FPL 2004, Puettmann and Milota 2017). The environmental burdens of generating the coproducts were accounted for by calculating the GWP credit. Electricity consumed for grinding the pallet parts used as fuel at the end-of-life was accounted for in this module. Electricity consumption for the grinder was assumed to be 13.3 kWh/OD t (Spinelli and others 2012). Transportation of wood fuel to users was taken into consideration and was assumed to be 50 km. In addition, the potential environmental benefits of recycled steel used in Module [A3] was calculated using data generated by the World Steel Association (2011).

2.8 Secondary Data Sources

Secondary data sources for raw material inputs, ancillary materials and packaging, transportation of materials and resources, fuels and energy for manufacturing, water sources, and waste streams used in this LCA study are shown in Table 13. Secondary data on fuels and electrical grid inputs were taken from the U.S. LCI Database and European datasets modified specifically to be representative of U.S. operations (DATASMART) (LTS 2017).

3 Life-Cycle Impact Assessment

3.1 Cradle-to-Grave Life-Cycle Assessment

LCIA results are presented in this section along with the information on end-of-life indicators used in the analysis (Table 14). The end-of-life stage began when the pallet left the use phase and describes the treatment options of wood pallets. These indicators showing waste and resource recovery were reported per UL Environment PCR clause 6.2 based on survey data. The pallet end-of-life treatment corresponded to the mass of 2.13 pallets (35.30 OD kg), and the various output flows showed the wood went where the highest output was wood material used for recycling.

Inventory and impact results for cradle-to-grave production of wooden pallets are presented in Table 15. Impact assessment results were presented for the weighted-average impact assessment for the four pallet types analyzed in this study. It was assumed that 78% of the pallets were stringer pallets and 22% were block pallets in line with the 2016 production data (Gerber 2018, Gerber and others 2020). In addition, it was assumed that 50% of the pallets produced were HD for both the stringer and block pallets.

Table 15 shows the summary results for the inventory analysis and impact assessment from cradle-to-grave along with Module [D]. For GW impact, the total was 10.4 kg CO_2e per FU for which raw material supply and manufacturing were the major contributors. Most of the GHGs were derived from the sawing and (kiln) drying processes at the raw material supply module (Bergman and Bowe 2008, 2011, 2012; Milota and Puettmann 2017; Hubbard and others 2020). A negative sign refers to environmental benefits, and Module [D] offset these GHG emissions when the environmental benefits were accounted for. Renewable biomass energy comprised about 40% of total primary energy consumption.

Table 16 presents the potential environmental benefits of beneficially used coproducts and end-of-life material. All core mandatory impact indicators were negative overall but the greatest opportunities for credit (i.e., negative environmental impacts) changed depending on the indicator and the material and energy recovery scenario assessed.

3.2 Additional Environmental Information

This section provides additional indicators related to life cycle of a wooden pallet including the environmental impacts from the use phase and biogenic carbon accounting results. The use phase for wooden pallets is subject to high variability and uncertainty. Therefore, scenario analyses were performed to calculate the resulting impact conforming to the PCR (Table 17). The emission factor for wooden pallet transportation was assumed at 0.0946 kg CO_2 eq/t.km (UL Environment 2019a).

A biogenic carbon balance was performed for the cradle-to-grave system boundary showing the biogenic carbon removal and emissions of wooden pallet life-cycle stages (Table 18). Biogenic carbon associated with the product recycled is reported in Module [C]. About 79.36 kg CO_2e were removed in Module [A1] in the pallets used to deliver 100,000 lb (45.4 metric tons) of pallet loads of product, whereas 76.63 kg CO_2e were emitted in Modules [A3] and [C].

4 Interpretation

In this section, the contribution analysis, completeness, sensitivity analysis, and consistency of the LCI results, conclusions, limitations, and recommendations are provided.

4.1 Life-Cycle Phase Contribution Analysis

The contribution analysis provided information on which life-cycle stage had a greater contribution to the selected environmental indicators. The product stage was composed of raw material supply Module [A1], raw material transport Module [A2], and pallet manufacturing Module [A3]. The use and repair stage was composed of Module [B1] and repair–reuse Module [B2]. The end-of-life was composed of Module [C]. Module [D], which was beyond the system boundary, reported additional benefits. Table 19 presents the results of the contribution analysis for five modules analyzed. The contribution analysis showed that the raw material supply Module [A1] and manufacturing Module [A3] were the major contributors to the impact categories investigated. Lower environmental impact can be achieved through improved performance of raw material processing Module [A1] and transportation Module [A2]. At the raw material supply Module [A1], kiln-drying is a major

Table 13—Secondary (background) data sources

Inputs	LCI data process and source	Geography	Year	Data quality assessment
A1 – raw material supply				
Wood raw material	CORRIM datasets: Sawn lumber, hardwood, green, rough, NE/NC USA, U Sawn lumber, softwood, rough, kiln-dried, at kiln, m^3 / SE_US Sawn lumber, softwood, green, rough, at sawmill, m^3 / SE_US Softwood lumber from dryer, m^3 / dry / PNW_US Sawn lumber, softwood, green, rough, at sawmill, m^3 / PNW_US Sawn lumber, softwood, rough, kiln-dried, at kiln, NE-NC NREL/RNA U Sawn lumber, softwood, rough, green, at sawmill, NE-NC/kg NREL/RNA U Plywood final, softwood, plywood mill, US, SE Plywood final, softwood, plywood mill, US, PNW OSB, packaged, at OSB plant, 2012	North America	2010–2018	**Technology:** very good; process models region-specific technology **Time:** good; data are less than 10 years old **Geography:** North America – Region specific; very good; data are representative of regional production
Electricity	Ecoinvent 3.5: Electricity, low voltage {US}| market group for | Cut-off, U	North America	2018	**Technology:** very good; process models average electricity technology specific to regional grids **Time:** very good; data are less than 5 years old **Geography:** very good
A2 – transportation				
Trucking	DATASMART (US EI 2.2): Transport, combination truck, diesel powered NREL/US U	North America	2017	**Technology:** very good; process models average North American technology **Time:** good; some data are less than 5 years old **Geography:** very good; data are representative of North American trucking
Rail	DATASMART (US EI 2.2): Transport, train, diesel powered NREL/US U	North America	2017	**Technology:** very good; process models average North American technology. **Time:** good; some data are less than 5 years old **Geography:** very good; data are representative of North American rail transport
A3 – product manufacturing				
Electricity	Ecoinvent 3.5: Electricity, low voltage {US}| market group for | Cut-off, U	North America	2018	**Technology:** very good; process models average electricity technology specific to regional grids **Time:** very good; data are less than 5 years old **Geography:** very good
Lubricating oil, grease	DATASMART (US EI 2.2): Lubricating oil, at plant/US-US-EI U	North America	2017	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American processes

Table 13—Secondary (background) data sources—con.

Inputs	LCI data process and source	Geography	Year	Data quality assessment
Plastic wrapping	DATASMART (US EI 2.2): Polyethylene, HDPE, granulate, at plant/kg/RER	North America	2017	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American processes
Cardboard packaging	DATASMART (US EI 2.2): Corrugated board, mixed fiber, single wall, at plant/RER with US electricity U	North America	2017	**Technology:** good; data are based on European producers and represent average of presently used technology with US electricity **Time:** very good; data are less than 5 years old **Geography:** fair; data are based on European producers
Natural gas	DATASMART (US EI 2.2): Natural gas, combusted in industrial equipment NREL/RNA U	North America	2017	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American natural gas production and combustion
Natural gas	DATASMART (US EI 2.2): Natural gas, combusted in industrial boiler NREL/RNA U	North America	2017	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American natural gas production and combustion
Diesel	DATASMART (US EI 2.2): Diesel, combusted in industrial equipment NREL/US U	North America	2017	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American diesel production and combustion
Gasoline	DATASMART (US EI 2.2): Gasoline produced and combusted, at equipment/US U	North America	2017	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American gasoline production and combustion
Liquid propane	DATASMART (US EI 2.2): Liquefied petroleum gas, combusted in industrial boiler NREL/US U	North America	2018	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American liquefied petroleum gas production and combustion
Woody biomass energy	CORRIM database: wood-fired boiler	North America	2015	**Technology:** very good; process represents combustion of woody biomass in an industrial boiler **Time:** good; data are within 2 years **Geography:** good, representative of North American wood boilers

Table 13—Secondary (background) data sources—con.

Inputs	LCI data process and source	Geography	Year	Data quality assessment
Fasteners (nails, staples, bolts, screws)	World Steel Association Dataset	Global	2018	**Technology:** very good; process represents steel products manufacturing **Time:** very good; data are less than 5 years old **Geography:** very good; process models average global technology
Fungicide	Fungicides, at regional storehouse/ US- US-EI U	North America	2017	**Technology:** good; data are based on European producers represents average of presently used technology with US electricity **Time:** very good; data are less than 5 years old **Geography:** fair; data are based on European producers
Waste landfilling	Ecoinvent 3.5: Process-specific burden, sanitary landfill {RoW}| processing | Cut-off, U	Global	2016	**Technology:** good; process models average global technology **Time:** very good; data are less than 5 years old **Geography:** good; data are representative of global practice
Paint	Alkyd paint, white, 60% in solvent, at plant/US- US-EI U	Global	2017	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American production
Ink	Ecoinvent 3.5: Chemical, organic {GLO}| production | Cut-off, U	Global	2018	**Technology:** good; process models average global technology **Time:** very good; data are less than 5 years old **Geography:** good; data are representative of global production
B2 – repair/reuse				
Wood raw material	CORRIM datasets: Processes	North America	2010–2018	**Technology:** very good; process models region-specific technology **Time:** good; data are less than 10 years old **Geography:** North America – region specific; very good; data are representative of regional production
Natural gas	DATASMART (US EI 2.2): Natural gas, combusted in industrial boiler NREL/RNA U	North America	2018	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American natural gas production and combustion
Diesel	DATASMART (US EI 2.2): Diesel, combusted in industrial equipment NREL/US U	North America	2018	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American diesel production and combustion

Table 13—Secondary (background) data sources—con.

Inputs	LCI data process and source	Geography	Year	Data quality assessment
Liquid propane	DATASMART (US EI 2.2): Liquefied petroleum gas, combusted in industrial boiler NREL/US U	North America	2018	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American liquefied petroleum gas production and combustion
Fasteners (nails, staples, bolts, screws)	World Steel Association Dataset	Global	2018	**Technology:** very good; process represents steel products manufacturing **Time:** very good; data are less than 5 years old **Geography:** very good; process models average global technology
Paint	Alkyd paint, white, 60% in solvent, at plant/US- US-EI U	North America	2017	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American production
Lubricating oil, grease	DATASMART (US EI 2.2): Lubricating oil, at plant/US- US-EI U	North America	2018	**Technology:** very good; process models average North American technology **Time:** very good; data are less than 5 years old **Geography:** very good; data are representative of North American processes
C – end-of-life-stage				
Waste landfilling	Ecoinvent 3.5: Process-specific burden, sanitary landfill {RoW}| processing | Cut-off, U	Global	2016	**Technology:** good; process models average global technology **Time:** very good; data are less than 5 years old **Geography:** good; data are representative of global practice
D – recovery and recycling potential				
Woody biomass energy	CORRIM database: wood-fired boiler	North America	2015	**Technology:** very good; process represents combustion of woody biomass in an industrial boiler **Time:** good; data are within 2 years **Geography:** good, representative of North American wood boilers

Table 14—Indicators describing end-of-life treatment and end-of-life output flows for 100,000 lb (45.4 metric tons) of pallet loads of product delivered

Indicator	Unit	Value
Inputs		
Pallet end-of-life treatment	OD kg	35.30
Outputs		
Components for reuse	OD kg	13.18
Materials for recycling	OD kg	14.25
Materials for energy recovery	OD kg	6.11
Exported energy (materials for energy recovery)[a]	MJ, NCV	103.79
Hazardous waste generated	kg	0.00

[a]Wood fuel net calorific value (NCV), 17 megajoule (MJ) per oven-dry (OD) kg (Puettmann and Milota 2017): 6.11 × 17 = 103.79.

Table 15—Results summary for cradle-to-grave inventory analysis and impact assessment of 100,000 lb (45.4 metric tons) of pallet loads of product delivered with wooden pallets, mass allocation

	Abbreviation	Unit	Total[a]	A1	A2	A3	B2	C	D
Core mandatory impact indicator									
Global warming potential	GWP	kg CO_2eq	10.39	3.58	2.42	3.60	0.78	0.01	–11.48
Acidification potential	AP	kg SO_2eq	6.30E–02	3.12E–02	1.39E–02	1.48E–02	3.10E–03	8.88E–05	–8.60E–03
Eutrophication potential	EP	kg Neq	2.13E–02	1.91E–03	8.88E–04	1.68E–02	1.74E–03	1.27E–05	–3.97E–04
Smog creation potential	SP	kg O_3-eq	1.46E+00	6.95E–01	4.00E–01	2.93E–01	6.83E–02	2.51E–03	–1.55E–01
Ozone depletion potential	ODP	kg CFC11eq	2.66E–07	1.12E–07	4.04E–09	1.25E–07	2.33E–08	1.48E–09	2.37E–08
Fossil fuel depletion	FD	MJ surplus	14.36	5.21	4.55	3.48	1.10	0.02	–26.64
Use of primary resources									
Total		MJ, NCV[b]	224.50	135.99	30.81	46.43	11.13	0.15	
Renewable primary energy	RP	MJ, NCV	2.61	1.198	0.054	1.166	0.187	0.001	—
Renewable primary energy biomass	RPRB	MJ, NCV	89.59	88.527	0.011	0.306	0.746	0.000	—
Nonrenewable primary energy (fossil)	NRPRF	MJ, NCV	117.26	39.230	30.301	38.482	9.111	0.135	—
Nonrenewable primary energy (nuclear)	NRPRN	MJ, NCV	15.04	7.035	0.439	6.472	1.087	0.010	—
Material resources consumption (nonfuel resources)									
Renewable materials	RM	kg	43.29	43.29	0	0	0	0	—
Nonrenewable materials	NRM	kg	0	0	0	0	0	0	—
Fresh water resources	FWR	m^3	2.55E–01	9.59E–02	2.79E–03	1.37E–01	1.91E–02	6.66E–05	—

[a]Totals included Modules A–C.
[b]NCV, net calorific value.

Table 16—Module D: 100,000 lb (45.4 metric tons) of pallet loads of product delivered with wooden pallets

Core mandatory impact indicator	Unit	Total	Coproducts-energy recovery[a]	End-of-life energy recovery[a]	Boards reused[b]	Steel recycled
GWP	kg CO_2eq	–11.48	–2.72	–7.09	–1.62	–0.05
AP	kg SO_2eq	–8.60E–03	4.43E–03	1.24E–03	–1.41E–02	–1.30E–04
EP	kg Neq	–3.97E–04	3.45E–04	1.23E–04	–8.66E–04	—
SP	kg O_3-eq	–1.55E–01	1.14E–01	4.64E–02	–3.15E–01	—
ODP	kg CFC11eq	2.37E–08	3.33E–08	4.14E–08	–5.09E–08	—
FD	MJ surplus	–26.64	–7.07	–17.20	–2.36	—

[a]Thermal energy generated substituted natural gas at boiler.
[b]Boards replaced virgin wood input.

Table 17—Scenario analysis for global warming impact of use phase on wooden pallet transportation for 100,000 lb (45.4 metric tons) of pallet loads of product delivered with wooden pallets

	Low	Average	High
Distance (km)	25	50	100
Transport metric[a] (t.km)	9.88E–01	1.98E+00	3.95E+00
GHGs per functional unit[b] (CO_2eq)	9.35E–02	1.87E–01	3.74E–01

[a]Used pallets transported by diesel tractor trailers.
[b]Emission factor is 0.0946 kg CO_2 eq/t.km

Table 18—Biogenic carbon inventory indicators

Additional inventory parameters	Unit	Total	A1	A2	A3	B2	C
Biogenic carbon removal from product	kg CO_2	–79.36	–79.36	—	—	—	—
Biogenic carbon emission from product	kg CO_2	76.63	—	—	14.65	—	61.99
Biogenic carbon removal from packaging	kg CO_2	–1.13	—	—	–1.13	—	—
Biogenic carbon emission from packaging	kg CO_2	1.13	—	—	—	1.13	—
Biogenic carbon emission from combustion of waste from renewable sources used in production	kg CO_2	0.00	—	—	0.00	—	—

Table 19—Cradle-to-grave life-cycle impact contribution analysis for 100,000 lb (45.4 metric tons) of pallet loads of product delivered

Core mandatory impact indicator	Unit	Total (%)	A1 (%)	A2 (%)	A3 (%)	B2 (%)	C (%)
GWP	kg CO_2eq	100	34	23	35	7	<1
AP	kg SO_2eq	100	49	22	23	5	<1
EP	kg Neq	100	9	4	79	8	<1
SP	kg O_3-eq	100	48	27	20	5	<1
ODP	kg CFC11eq	100	42	2	47	9	<1
FD	MJ surplus	100	36	32	24	8	<1

contributor to the GW impact of lumber manufacturing. Adoption of new drying technologies [i.e., the progressive (continuous flow) dryers] can lead to greater environmental performance (Bergman 2021, Bond and Espinoza 2016). The disposal (end-of-life) stage [C], which includes the portion of wooden pallets disposed to landfills, has minor contribution to overall environmental impacts.

4.2 Uncertainty and Sensitivity Analysis

Sensitivity analysis is performed to identify the parameters that have great influence on the environmental impact of the system. Defining sensitive parameters may help mitigate the potential sources for uncertainties. In this study, the sensitivity analysis was performed by altering the selected parameters by 20%. The selected parameters included the electricity input, amount of fasteners used, and amount of wood material input to the wooden pallet manufacturing system [A3]. The results of the sensitivity analysis are presented in Table 20. The increase in wood material input had the greatest effect on the GWP results, about 12% output variance. Conversely, a 20% increase in other two parameters resulted in a small variation in the GWP impact of about 2% to 3%.

4.3 Limitations

The industry-average LCA was performed in this study using weight-averaged primary data from U.S. wooden pallet manufacturers. The wide variety of wooden pallets manufactured in the U.S. industry makes development of the industry-average wooden pallet LCI a complex task. Focusing on the highest production pallet, the GMA-style pallet with the 48- by 40-in. footprint, the RSL and load carrying capacity of four pallet types were used to calculate the FU. Therefore, weight load capacity and durability had great influence on the overall environmental performance. Including the repair–remanufacturing stage to perform cradle-to-grave analysis requires accounting

Table 20—Sensitivity of parameters on overall impact for 100,000 lb (45.4 metric tons) of pallet loads of product delivered

Core mandatory impact indicator	Unit	Base case	Electricity		Fastener		Wood material input	
			–20%	+20%	–20%	+20%	–20%	+20%
GWP	kg CO_2eq	10.4	10.1	10.7	10.1	10.6	9.2	11.59
AP	kg SO_2eq	6.30E–02	6.21E–02	6.38E–02	6.22E–02	6.37E–02	5.40E–02	7.20E–02
EP	kg Neq	5.00E–03	4.74E–03	5.26E–03	4.98E–03	5.02E–03	4.44E–03	5.56E–03
SP	kg O_3-eq	1.46E+00	1.45E+00	1.47E+00	1.45E+00	1.47E+00	1.24E+00	1.68E+00
ODP	kg CFC11eq	2.66E–07	2.44E–07	2.89E–07	2.66E–07	2.66E–07	2.43E–07	2.90E–07
FD	MJ surplus	14.4	14.2	14.6	14.3	14.5	12.4	16.32

for the extended service life after repair. A conservative approach was used in the study by assuming a pallet can only be repaired a single time; typically, wooden pallets can be repaired multiple times. Accounting for multiple repairs would probably decrease the environmental impacts for a cradle-to-grave analysis because less virgin wood material would be needed and RSL will be longer. Data for the volume of wood material per pallet were not available at all facilities because a typical pallet facility manufactures pallets in a wide variety of sizes. The study evaluated the most commonly used pallets in the sector, the GMA-style pallet (about 35% of total production in 2016). Specialty pallets constituted a large portion of the manufactured pallets, about 39% (Gerber 2018, Gerber and others 2020).

4.4 Conclusions and Recommendations

This study presents a comprehensive industry-average environmental impact analysis of the wooden pallet manufacturing and recycling sector in the United States. The data were collected from wooden pallet facilities throughout the United States. The industry-average LCI developed was representative of the United States for an average wooden pallet produced. The scope and content of this report was in line with the wooden pallet PCR, which will be used to develop an industry-average EPD.

Raw material supply Module [A1] and product manufacturing Module [A3] were the major contributors to the overall environmental impact. The raw material supply phase, which includes lumber production, constituted about 34% of the GHG emissions. Wooden pallets showed notable GHG benefits when potential environmental benefits were considered [D], such as waste wood being used as fuel to replace natural gas at boilers.

Conducting a cradle-to-grave analysis is a complex task for many products. It is especially complex for wood pallets because of the many wood species used, types and sizes of pallets produced, highly dispersed production, and vertical integration of some production facilities handling both new and repaired–remanufacturing pallets. However, without the cradle-to-grave analysis, the full measure of the environmental benefits of the industry itself would not be captured including the increasing number of pallets being repaired or remanufactured (Gerber and others 2020, Shiner 2018). It is likely that a future sectoral analysis would show improved environmental performance because producers will have a more accurate picture of their environmental impacts across the whole supply chain.

Wood pallets and their components are easy to repair. This study considered a single repair, which was conservative and thus probably overestimated the environmental impacts of a sectoral analysis as indicated by the repair and reuse stage [B2]. If more repairs were considered, less virgin wood material would be required in addition to extending the RSL, which would probably have a substantial positive environmental impact because of how much the wood material inputs affected the GHG profile. This would be consistent with what was found on the recovered flooring and framing lumber LCA analysis (Bergman and others 2013).

Tracking pallets during the use phase could help lower the uncertainty and variability. However, the pallet industry does not control which goods are transported or warehoused using their pallets. Some wood pallet pooling organizations have recorded these data, but they are highly confidential given the economic advantage this information has (Ren and others 2018). A sectoral analysis would be needed to capture enough high-quality data and to be representative of the wood pallet industry.

5 Report Review

A review of this LCA report was conducted to ensure that the study methodology, data collection, and analyses were scientifically sound and in conformance with internationally accepted standards and the PCR. In most cases, technical and editorial comments provided by the reviewers were incorporated into the final document. Internal reviews for this report were provided by Dr. Steve Hubbard, USDA Forest Service; Dr. Brad Gething, National Wooden Pallet and Container Association; and James Salazar, Coldstream Consulting.

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VT. 2018. FasTrack protocol: Virginia Tech unit-load material handling FasTrack. Blacksburg, VA: Virginia Tech, Center for Packaging and Unit Load Design. https://www.unitload.vt.edu/wp-content/uploads/2018/06/CPULD-FasTrack-Info-2018.pdf.

VT. 2019. Evaluation of the durability of four wooden pallet designs using Virginia Tech's FasTrack simulation. Test Report No: 2019-0024. Blacksburg, VA: Virginia Tech, Center for Packaging and Unit Load Design.

World Steel Association. 2011. Life cycle assessment methodology report. Brussels, Belgium: World Steel Association.

Appendix A—Wood Species

Common wood species used in wooden pallet manufacturing[a]

Class number	Class name	Species
	North American hardwoods	
1	High-density eastern hardwoods	American beech Ash (green, white) Birch (sweet, yellow) Black cherry Black locust Dogwood Elm (rock, slippery) Hickory Maple (black, red, sugar) Persimmon Tan oak
2		Bigleaf maple Oregon ash
3	Medium-density eastern hardwoods	Ash (black, pumpkin) Hackberry Maple (silver, striped) Magnolia Paper birch Sweetgum Sycamore Tupelo
4	Western hardwoods	California black oak Cascara Chinquapin Madrone Myrtle Oregon white oak
6		Red alder
7	Low-density eastern hardwoods	American basswood Aspen (bigtooth, quaking) Buckeye Butternut Catalpa Cottonwood (balsam, black) Eastern poplar
21	Eastern oaks	Red oak White oak
29		Yellow poplar
	North American softwoods	
11	Douglas-fir	Douglas-fir (coast, interior west, interior north, interior south) Western larch
12	Hem–Fir	Fir (California red, grand, noble, Pacific silver, white) Hemlock (western, mountain)
13	SPF	Baldcypress Eastern hemlock Fir (balsam, subalpine) Pine (eastern white, jack, lodgepole, Monterey, Norway, Ponderosa, sugar, western white) Redwood Southern pine (pitch, pond) Spruce (black, Engelmann, red, sitka, Virginia, white) Western redcedar

Common wood species used in wooden pallet manufacturing[a]—con.

Class number	Class name	Species
	North American softwoods—con.	
14	Low-density softwoods	Cedar (Alaska, Atlantic white, eastern red, incense, northern white, Port Orford)
22	SYP	Southern yellow pine (loblolly, longleaf, shortleaf, slash)
	European species	
31	Imported hardwoods	Kapur Keruing Menqkulanq
32	Dense European hardwoods	Ash Beech Oak Plane
33	Dense European softwoods	Douglas-fir Larch (European, Japanese) Pine (jack, maritime, Scots)
34	Medium dense woods	Dutch elm Hyrbrid larch Pine (Corsican, lodgepole) Poplar (black Italian, grey) Redwood Silver fir
35	Whitewood	English elm Sitka spruce (Canada) Whitewood
36	Common European softwoods	Radiata pine Spruce (black, Norway, white, Sitka) White willow
37		Hybrid poplar
	South American and other species	
41		*Radiata pine* (Chile)
42		*Gmelina arborea* (Costa Rica)
43		*Pinus caribaea* (Venezuela)
44		*Pinus elliottii*
45		*Pinus taeda*
46		*Eucalyptus grandis* (Uruguay)

[a]MHI (2019).

Appendix B—Pallet Design System Specifications of the Pallets Analyzed

The following pallet design systems have been used with permission from the National Wooden Pallet & Container Association (NWPCA).

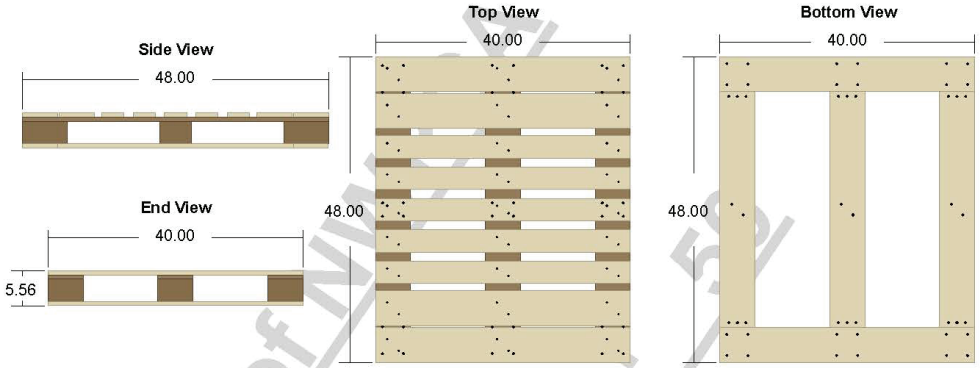
PALLET DESIGN SYSTEM Version 6.1

Pallet Specification Sheet — **All dimensions in inches**

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Heavy Block
Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture



Components

Top Deck:
Style: Deckboard/Stringerboard **Type:** New Lumber

Number	Thickness	Width	Length
5	0.688	3.500	40.00
4	0.688	5.500	40.00

Volume: 7.5 bd ft
Mat Assembly Method, Mat Fasteners Clinched

Bottom Deck:
Style: Perimeter Base **Type:** New Lumber

Number	Thickness	Width	Length
2	0.688	5.500	40.00
3	0.688	5.500	37.00

Volume: 5.0 bd ft

Top Stringerboards:
Type: New Lumber

Number	Thickness	Width	Length
3	0.688	5.500	48.00

Volume: 3.8 bd ft

Blocks:
Type: Lumber **Grain Orientation:** Sidegrain Nailing

Number	Width	Length	Height
3	5.500	5.00	3.500
6	5.500	7.00	3.500

Volume: 7.6 bd ft

Materials

Fasteners:

	Mat	Block
Fastener ID:	2" Mat Fast	3" Blk Fast
Fastener Type:	Annularly Threaded Nail	Annularly Threaded Nail
Fastener Length:	2.00	3.00
Thread Length:	0.75	2.25
Thread Diameter:	0.128	0.128
Wire Diameter:	0.112	0.112
Head Diameter:	0.280	0.280
Rings:	20	40
Pitch:	0.038	0.056
MIBANT Angle:	36	36
FWC:	6.50	6.50
Total Number:	54	84

New Lumber:
Lumber ID:

Species Class	Grade	Lumber Mix
High Density Eastern Hardwoods	Standard &BTR	50 %
Medium Density Eastern Hardwoods	Standard &BTR	50 %

Moisture Content (at manufacture and assembly): Green

Total New Lumber Volume: 24.0 bd ft

Spec Sheet Notes:

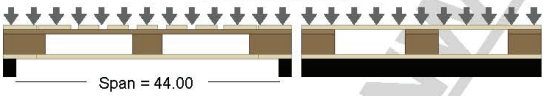
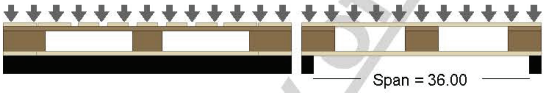
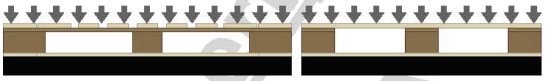
PALLET DESIGN SYSTEM Version 6.1
Pallet Structural Analysis

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Heavy Block
Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

General Load Type: Uniformly Distributed - Full Pallet Coverage
Load Weight Variability: Medium
Service Environment: Dry Environment (EMC <= 19%)

Support Condition (Side View / End View)	Safe Maximum Load	Deflection at Maximum Load	User Specified Deflection Limit	Maximum Load for Deflection Limit	Critical Member or Connection
Racked Across Length 2 Beam Support 	2529 lbs.	0.80 in.	----	----	Interior Butted Board
Racked Across Width 2 Beam Support 	3029 lbs.	0.65 in.	----	----	Interior Top Deckboard
Warehouse Storage Stacked 1 Unit Load High 	9457 lbs.	0.27 in.	0.25 in.	NA	Center Top Stringerboard

Pallet Design System (PDS)
Developed and owned by:
National Wooden Pallet and Container Association (NWPCA)
Research and development for early versions of PDS were conducted in cooperation with:
Center for Unit Load Design, Virginia Tech Department of Wood Science and Forest Products;
U.S.D.A. Forest Service and Forest Products Laboratory; APA - The Engineered Wood Association;
Software Technologies Laboratory, Virginia Tech Department of Industrial and Systems Engineering

PALLET DESIGN SYSTEM Version 6.1
Pallet Durability Analysis

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Heavy Block
Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

Pallet Service Life Analysis

The **Pallet Service Life Analysis** simulates a series of forces and impacts applied to the pallet during each handling cycle. The frequency and severity of these impacts are estimates based on laboratory measurements, warehouse observations, and the Virginia Tech FasTrack Handling Cycle. The resistance to damage and the damage level requiring component repair or replacement are based on laboratory testing and the NWPCA Uniform Standard for Wood Pallets.

Service Environment Conditions:
Average Handling and Treatment, Medium-Duty Loads, Dry Environment (EMC <= 19%)

Predicted Service Life: 32 Cycles **Predicted Cycles until First Repair:** 8

Results from Handling Cycle Simulation

Pallet Components		Cycles To First Repair	Cycles To First Replacement	Number of Times Replaced	Limits Pallet Service Life	Relative Component Damage during Simulation
Top Leadboards	(2)	11	19	1		
Top InteriorBoards	(6)					
Top CenterBoard	(1)					
Perimeter-base Outer Boards	(2)		8	3	Yes	
Perimeter-base Butted Boards	(3)	19	10	2		
Exterior Top StringerBoards	(2)					
Interior Top StringerBoard	(1)					
Corner Blocks	(4)					
Edge Blocks	(2)					
End Blocks	(2)					
Center Block	(1)					

PALLET DESIGN SYSTEM Version 6.1
Pallet Physical Property Analysis

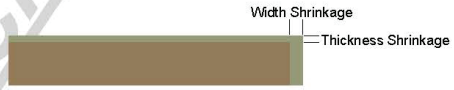
Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Heavy Block
Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

	At Manufacture	At 25% MC	At 19% MC	At 15% MC	At 12% MC
Average Pallet Weight	113 lbs.	81 lbs.	77 lbs.	75 lbs.	73 lbs.

Dimensional Change due to Wood Drying

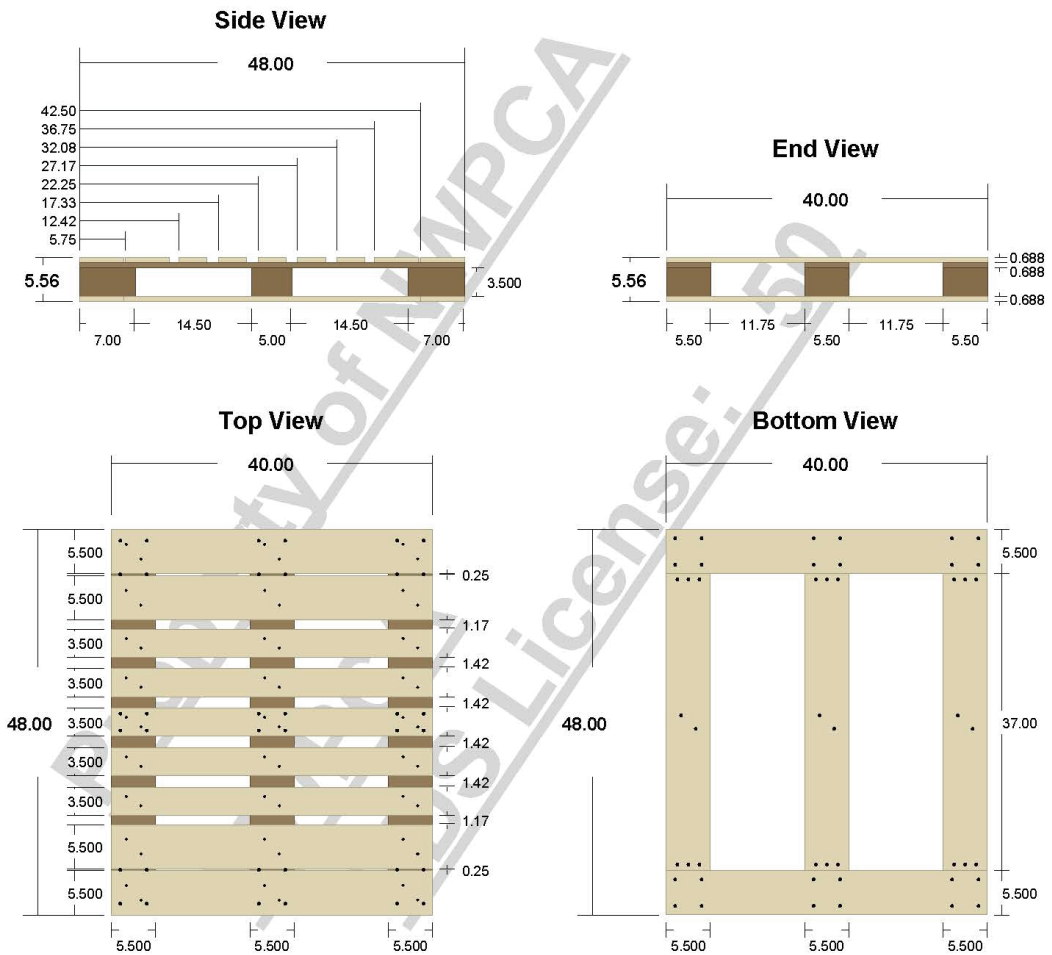


Component	Original Dimension	Shrinkage from Manufacture to 19% MC	Shrinkage from Manufacture to 15% MC
Top Deckboards	0.688 in. Thickness 3.500 in. Width 5.500 in. Width	0.016 in. (+/- 0.005 in.) 0.081 in. (+/- 0.023 in.) 0.128 in. (+/- 0.037 in.)	0.023 in. (+/- 0.007 in.) 0.117 in. (+/- 0.034 in.) 0.184 in. (+/- 0.053 in.)
Top Stringerboards	0.688 in. Thickness 5.500 in. Width	0.016 in. (+/- 0.005 in.) 0.128 in. (+/- 0.037 in.)	0.023 in. (+/- 0.007 in.) 0.184 in. (+/- 0.053 in.)
Blocks	3.500 in. Height 5.500 in. Width	0.081 in. (+/- 0.023 in.) 0.128 in. (+/- 0.037 in.)	0.117 in. (+/- 0.034 in.) 0.184 in. (+/- 0.053 in.)
Bottom Deckboards	0.688 in. Thickness 5.500 in. Outer Board Width 5.500 in. Butted Board Width	0.016 in. (+/- 0.005 in.) 0.128 in. (+/- 0.037 in.) 0.128 in. (+/- 0.037 in.)	0.023 in. (+/- 0.007 in.) 0.184 in. (+/- 0.053 in.) 0.184 in. (+/- 0.053 in.)

PALLET DESIGN SYSTEM Version 6.1
2-D Pallet Drawings

All dimensions in inches

Pallet ID: 48x40 Heavy Block
Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

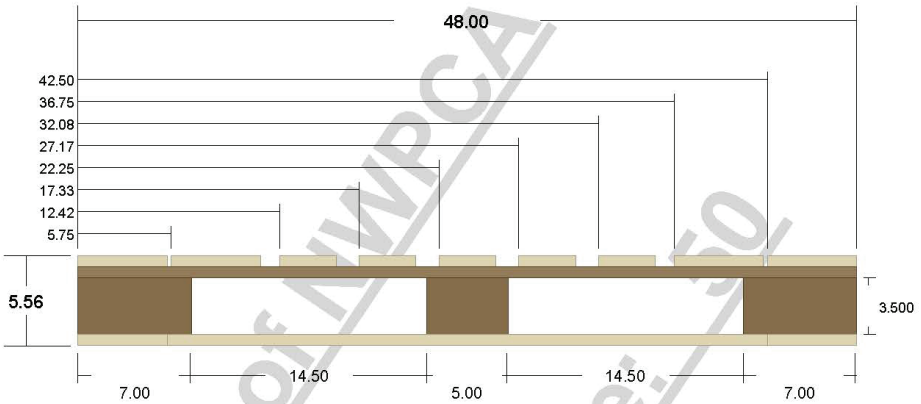
Pallet Drawing - Side and End View

All dimensions in inches

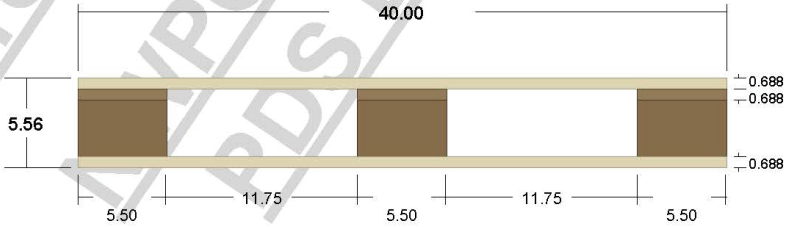
Pallet ID: 48x40 Heavy Block

Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

Side View



End View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

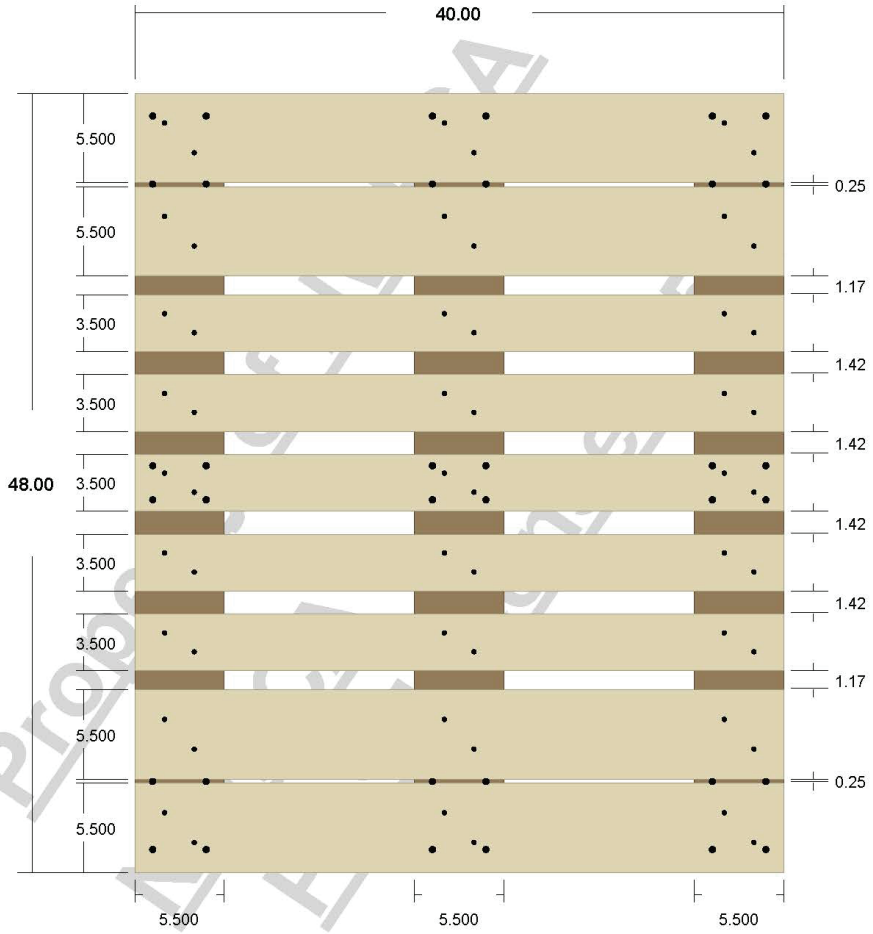
Pallet Drawing - Top View

All dimensions in inches

Pallet ID: 48x40 Heavy Block

Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

Top View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

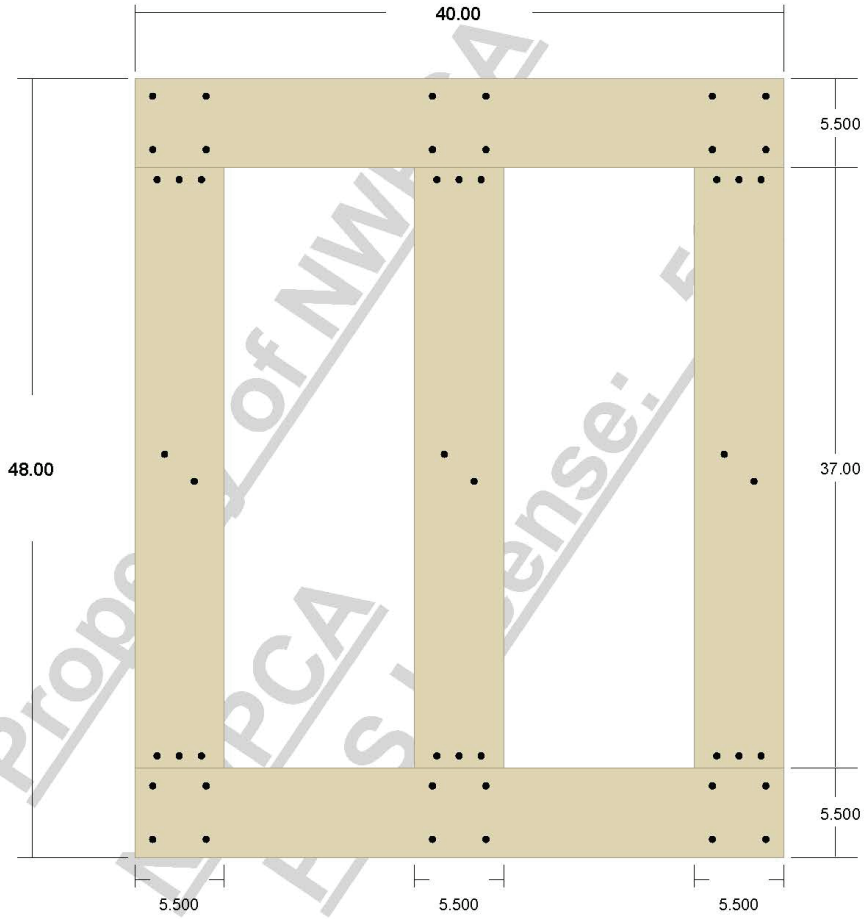
Pallet Drawing - Bottom View

All dimensions in inches

Pallet ID: 48x40 Heavy Block

Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

Bottom View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

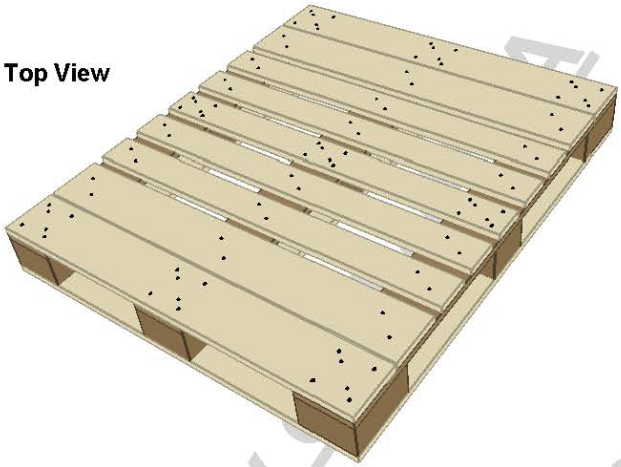
3-D Pallet Drawings

All dimensions in inches

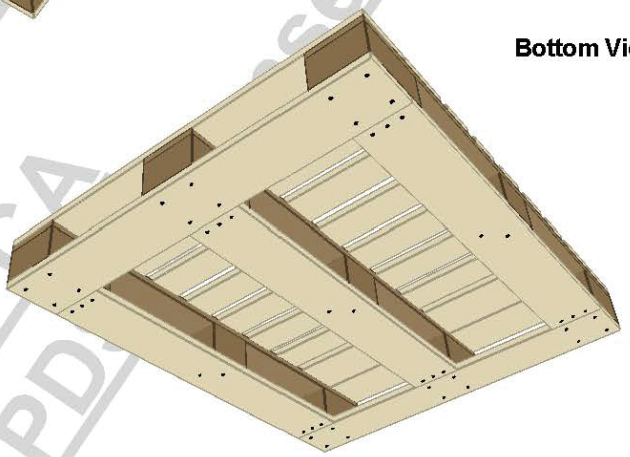
Pallet ID: 48x40 Heavy Block

Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

Top View



Bottom View



Customer:

Prepared by:

NWPCA

PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

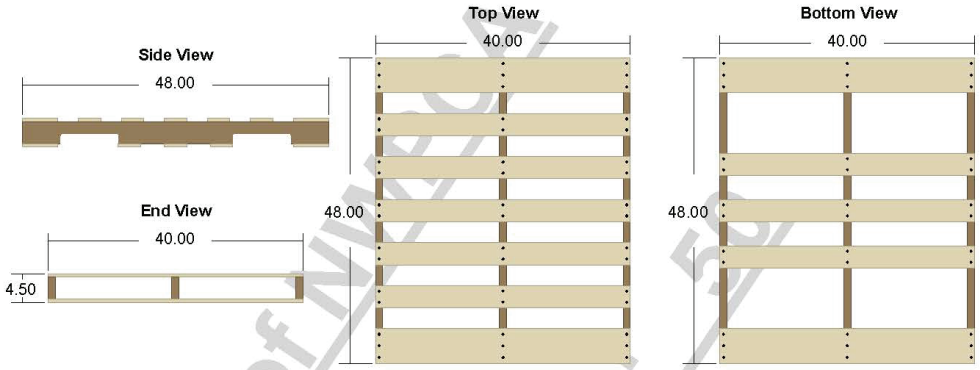
Pallet Specification Sheet

All dimensions in inches

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Light Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture



Components

Top Deck:

Style: Deckboard **Type:** New Lumber

Number	Thickness	Width	Length
5	0.500	3.500	40.00
2	0.500	5.500	40.00

Volume: 4.0 bd ft

Bottom Deck:

Style: Deckboard **Type:** New Lumber

Number	Thickness	Width	Length
3	0.500	3.500	40.00
2	0.500	5.500	40.00

Volume: 3.0 bd ft

Stringers:

Type: New Lumber

Number	Width	Height	Length
3	1.125	3.500	48.00

Volume: 3.9 bd ft
Partial 4-way Entry Notch:
Depth: 1.500 Length: 9.00 Location: 6.00 Radius: 0.75

Materials

Fasteners:

Fastener ID:	2-1/4 x .112 SS
Fastener Type:	Helically Threaded Nail
Fastener Length:	2.25
Thread Length:	1.25
Thread Diameter:	0.128
Wire Diameter:	0.112
Head Diameter:	0.280
Flutes:	4
Helixes:	5.4
Pitch:	0.231
Thread Angle:	66
MIBANT Angle:	36
FWC:	2.52
Total Number:	84

New Lumber:

Lumber ID:

Species Class	Grade	Lumber Mix
High Density Eastern Hardwoods	Standard &BTR	50 %
Medium Density Eastern Hardwoods	Standard &BTR	50 %

Moisture Content (at manufacture and assembly): Green

Total New Lumber Volume: 10.9 bd ft

Spec Sheet Notes:

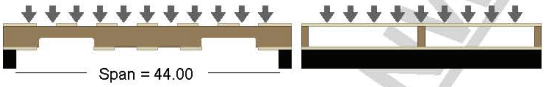
PALLET DESIGN SYSTEM Version 6.1
Pallet Structural Analysis

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Light Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

General Load Type: Uniformly Distributed - Partial Pallet Coverage
Load Begins: 3.00 in. from Pallet End 3.00 in. from Pallet Side
Load Weight Variability: Medium
Service Environment: Dry Environment (EMC <= 19%)

Support Condition (Side View / End View)	Safe Maximum Load	Deflection at Maximum Load	User Specified Deflection Limit	Maximum Load for Deflection Limit	Critical Member or Connection
Racked Across Length 2 Beam Support  Span = 44.00	1002 lbs.	0.65 in.	----	----	Center Stringer
Racked Across Width 2 Beam Support  Span = 36.00	1029 lbs.	1.01 in.	----	----	Interior Bottom Deckboard
Warehouse Storage Stacked 1 Unit Load High 	2697 lbs.	0.29 in.	0.25 in.	NA	Interior Top Deckboard

Lateral Collapse Resistance

Low | Medium | Good | Excellent

LCR Indicator = 1.51

PALLET DESIGN SYSTEM Version 6.1
Pallet Durability Analysis

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Light Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

Pallet Service Life Analysis

The **Pallet Service Life Analysis** simulates a series of forces and impacts applied to the pallet during each handling cycle. The frequency and severity of these impacts are estimates based on laboratory measurements, warehouse observations, and the Virginia Tech FasTrack Handling Cycle. The resistance to damage and the damage level requiring component repair or replacement are based on laboratory testing and the NWPCA Uniform Standard for Wood Pallets.

Service Environment Conditions:
Average Handling and Treatment, Medium-Duty Loads, Dry Environment (EMC <= 19%)

Predicted Service Life: 6 Cycles **Predicted Cycles until First Repair:** 2

Results from Handling Cycle Simulation

Pallet Components		Cycles To First Repair	Cycles To First Replacement	Number of Times Replaced	Limits Pallet Service Life	Relative Component Damage during Simulation
Top Leadboards	(2)	2	3	1	Yes	
Top InteriorBoards	(5)		6			
Bottom Leadboards	(2)	2	4	1		
Bottom InteriorBoards	(3)					
Exterior Stringers	(2)	3				
Interior Stringers	(1)					

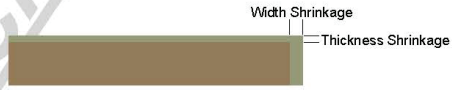
PALLET DESIGN SYSTEM Version 6.1
Pallet Physical Property Analysis

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Light Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

	At Manufacture	At 25% MC	At 19% MC	At 15% MC	At 12% MC
Average Pallet Weight	49 lbs.	35 lbs.	33 lbs.	32 lbs.	31 lbs.



Dimensional Change due to Wood Drying

Component	Original Dimension	Shrinkage from Manufacture to 19% MC	Shrinkage from Manufacture to 15% MC
Top Deckboards	0.500 in. Thickness 3.500 in. Width 5.500 in. Width	0.012 in. (+/- 0.003 in.) 0.081 in. (+/- 0.023 in.) 0.128 in. (+/- 0.037 in.)	0.017 in. (+/- 0.005 in.) 0.117 in. (+/- 0.034 in.) 0.184 in. (+/- 0.053 in.)
Stringers	3.500 in. Height 1.125 in. Width	0.081 in. (+/- 0.023 in.) 0.026 in. (+/- 0.008 in.)	0.117 in. (+/- 0.034 in.) 0.038 in. (+/- 0.011 in.)
Bottom Deckboards	0.500 in. Thickness 3.500 in. Width 5.500 in. Width	0.012 in. (+/- 0.003 in.) 0.081 in. (+/- 0.023 in.) 0.128 in. (+/- 0.037 in.)	0.017 in. (+/- 0.005 in.) 0.117 in. (+/- 0.034 in.) 0.184 in. (+/- 0.053 in.)

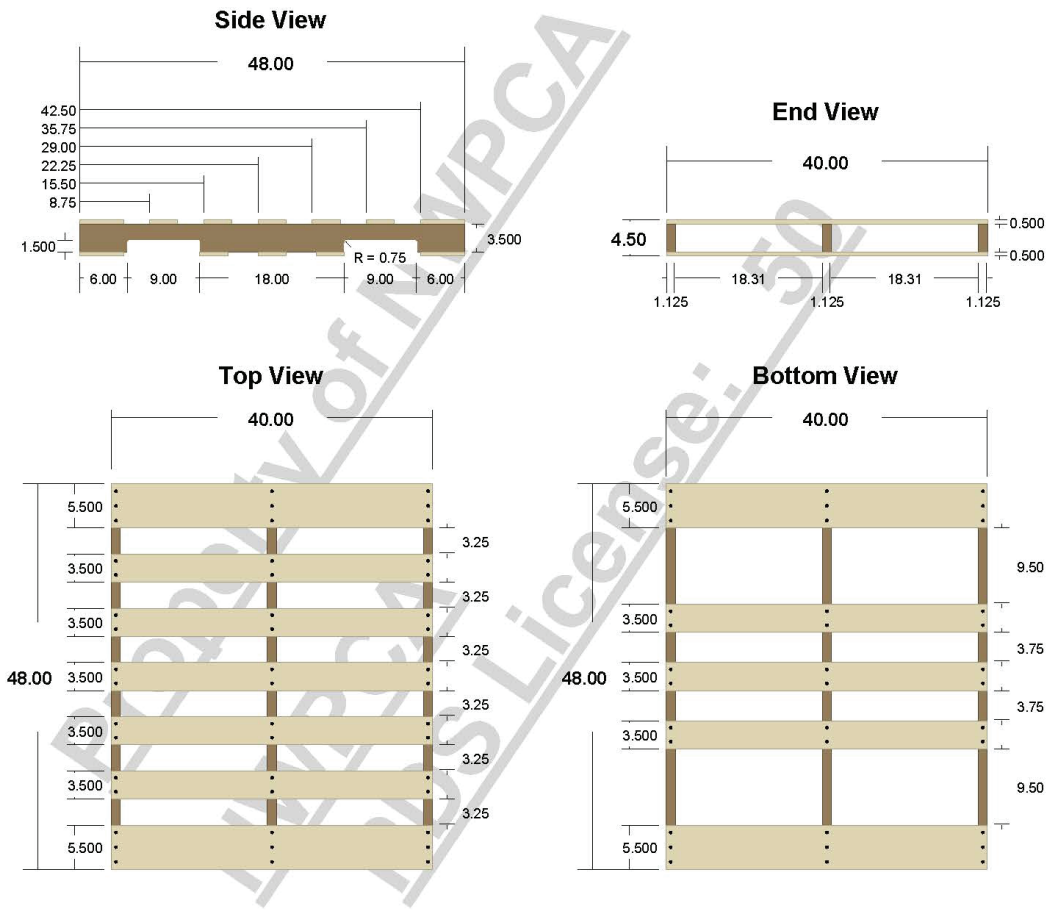
PALLET DESIGN SYSTEM Version 6.1

2-D Pallet Drawings

All dimensions in inches

Pallet ID: 48x40 Light Stringer

Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

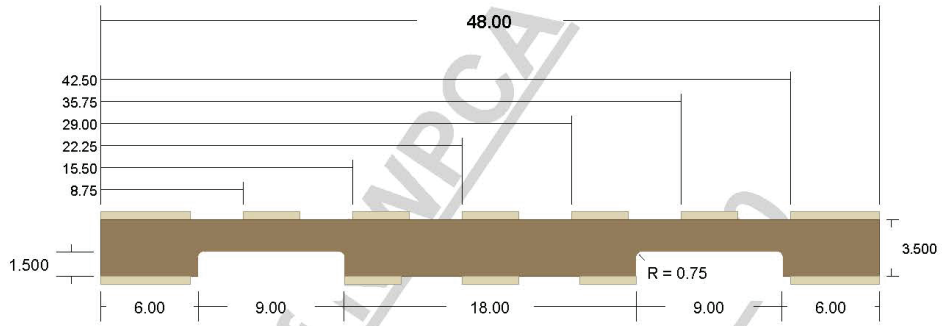
Pallet Drawing - Side and End View

All dimensions in inches

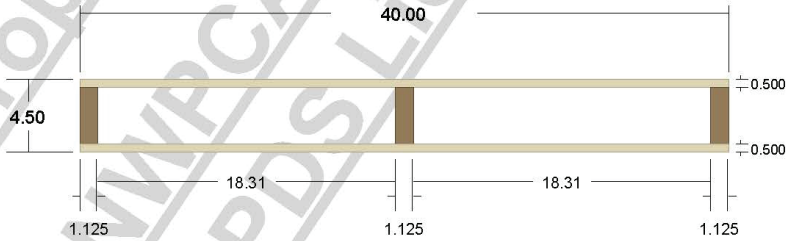
Pallet ID: 48x40 Light Stringer

Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

Side View



End View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

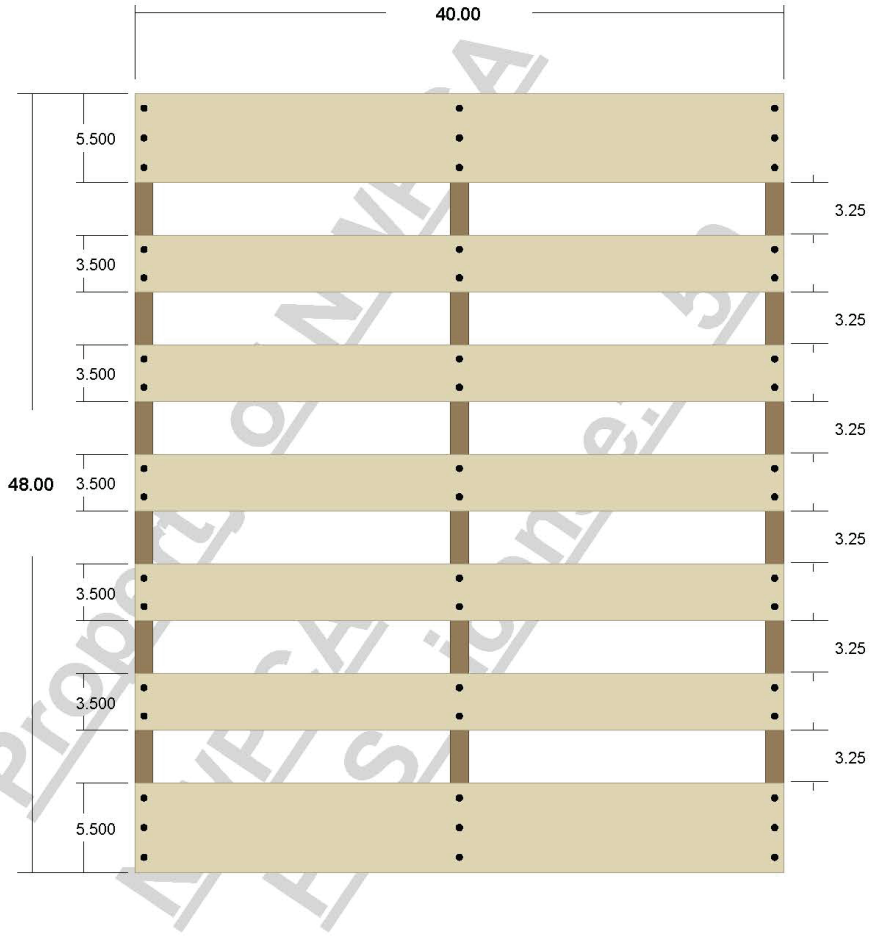
Pallet Drawing - Top View

All dimensions in inches

Pallet ID: 48x40 Light Stringer

Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

Top View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

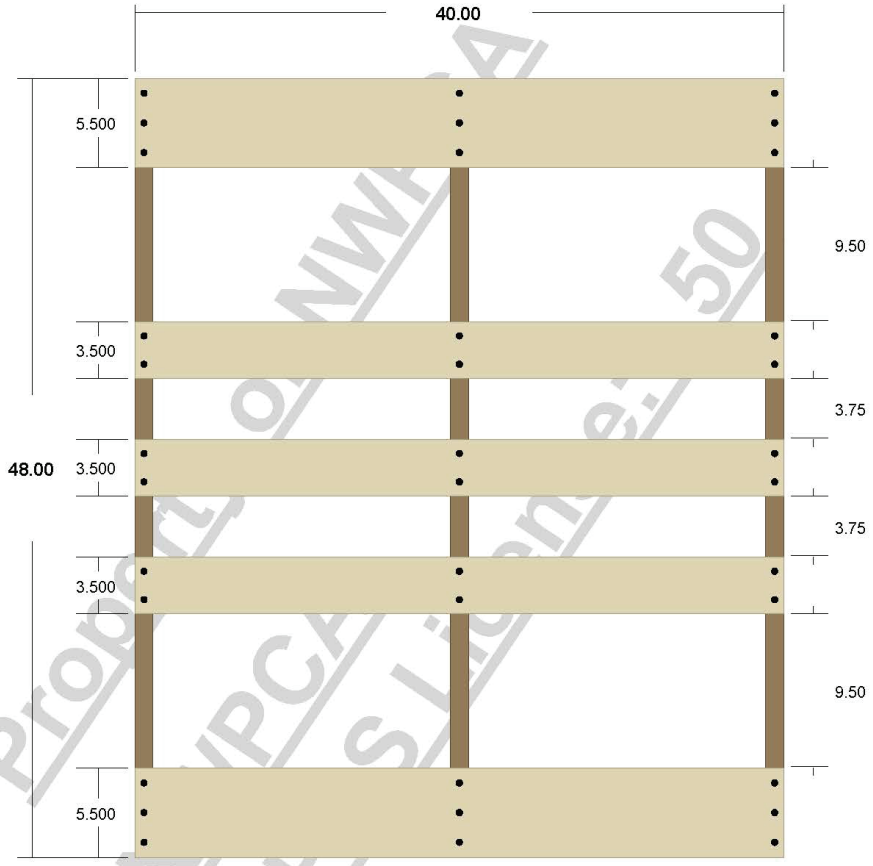
Pallet Drawing - Bottom View

All dimensions in inches

Pallet ID: 48x40 Light Stringer

Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

Bottom View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

3-D Pallet Drawings

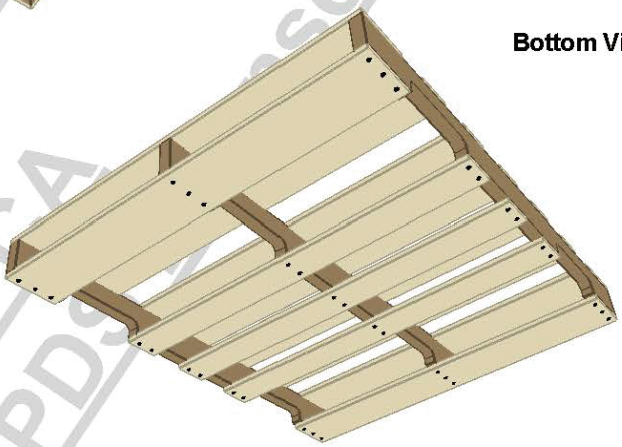
All dimensions in inches

Pallet ID: 48x40 Light Stringer

Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

Top View

Bottom View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

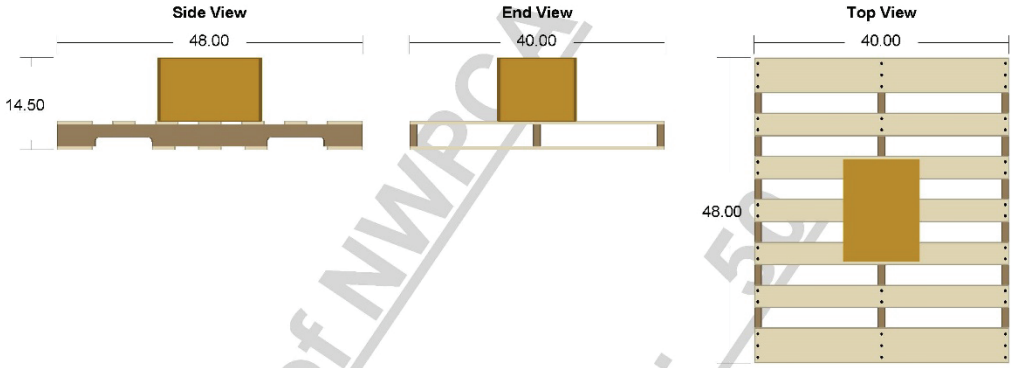
PALLET DESIGN SYSTEM Version 6.1
Unit Load Specification and Drawings

All dimensions in inches

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Light Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture



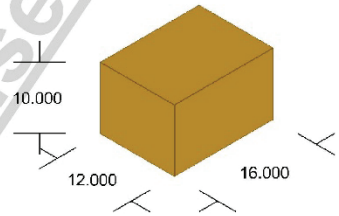
Container Type: Corrugated Box

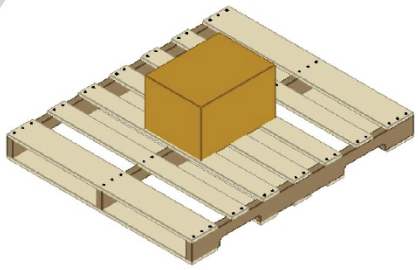
Box Style: Regular Slotted Container (RSC) #0201

Weight per Box: 20.0 lbs.

Number of Boxes per Layer: 1
Number of Layers per Unit Load: 1 **Single Stacked**
Number of Boxes per Unit Load: 1
Total Weight of Load: 20.0 lbs.
Total Height of Load: 10.000 in.

Outside Dimensions:
Length: 16.000
Width: 12.000
Depth: 10.000 *





PALLET DESIGN SYSTEM Version 6.1

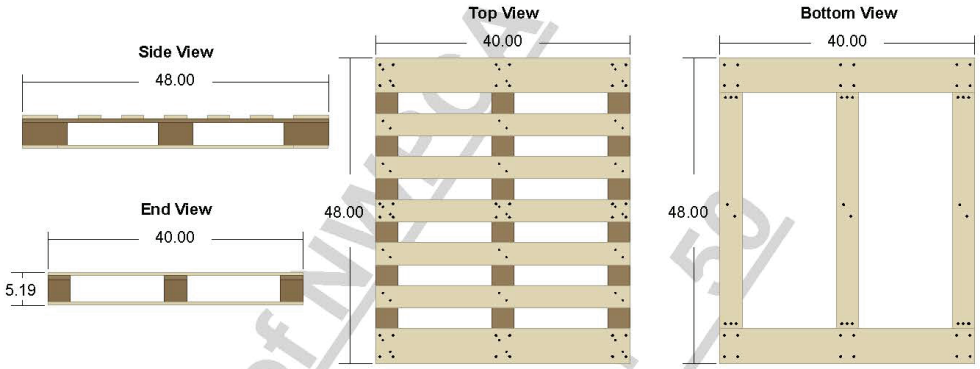
Pallet Specification Sheet

All dimensions in inches

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Light Block
Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture



Components

Top Deck:

Style: Deckboard/Stringerboard **Type:** New Lumber

Number	Thickness	Width	Length
5	0.500	3.500	40.00
2	0.500	5.500	40.00

Volume: 4.0 bd ft
Mat Assembly Method, Mat Fasteners Clinched

Bottom Deck:

Style: Perimeter Base **Type:** New Lumber

Number	Thickness	Width	Length
2	0.500	5.500	40.00
3	0.500	3.500	37.00

Volume: 2.9 bd ft

Top Stringerboards:

Type: New Lumber

Number	Thickness	Width	Length
3	0.688	3.500	48.00

Volume: 2.4 bd ft

Blocks:

Type: Lumber **Grain Orientation:** Sidegrain Nailing

Number	Width	Length	Height
3	3.500	5.50	3.500
6	3.500	7.00	3.500

Volume: 5.0 bd ft

Materials

Fasteners:

	Mat	Block
Fastener ID:	2" Mat Fast	3" Blk Fast
Fastener Type:	Annularly Threaded Nail	Annularly Threaded Nail
Fastener Length:	2.00	3.00
Thread Length:	0.75	2.00
Thread Diameter:	0.128	0.128
Wire Diameter:	0.112	0.112
Head Diameter:	0.280	0.280
Rings:	20	40
Pitch:	0.038	0.050
MIBANT Angle:	36	36
FWC:	6.50	6.52
Total Number:	42	84

New Lumber:

Lumber ID:

Species Class	Grade	Lumber Mix
High Density Eastern Hardwoods	Standard &BTR	50 %
Medium Density Eastern Hardwoods	Standard &BTR	50 %

Moisture Content (at manufacture and assembly): Green

Total New Lumber Volume: 14.2 bd ft

Spec Sheet Notes:

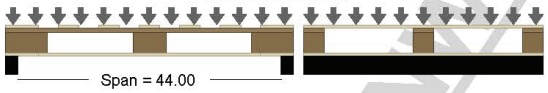
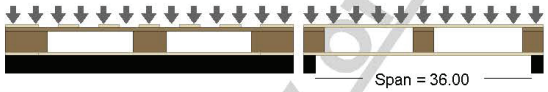
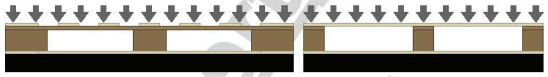
PALLET DESIGN SYSTEM Version 6.1
Pallet Structural Analysis

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Light Block
Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

General Load Type: Uniformly Distributed - Full Pallet Coverage
Load Weight Variability: Medium
Service Environment: Dry Environment (EMC <= 19%)

Support Condition (Side View / End View)	Safe Maximum Load	Deflection at Maximum Load	User Specified Deflection Limit	Maximum Load for Deflection Limit	Critical Member or Connection
Racked Across Length 2 Beam Support 	1491 lbs.	0.80 in.	----	----	Interior Butted Board
Racked Across Width 2 Beam Support 	1592 lbs.	0.94 in.	----	----	Interior Top Deckboard
Warehouse Storage Stacked 1 Unit Load High 	4145 lbs.	0.31 in.	0.25 in.	NA	Interior Top Deckboard

Pallet Design System (PDS)
Developed and owned by:
National Wooden Pallet and Container Association (NWPCA)
Research and development for early versions of PDS were conducted in cooperation with:
Center for Unit Load Design, Virginia Tech Department of Wood Science and Forest Products;
U.S.D.A. Forest Service and Forest Products Laboratory; APA - The Engineered Wood Association;
Software Technologies Laboratory, Virginia Tech Department of Industrial and Systems Engineering

PALLET DESIGN SYSTEM Version 6.1
Pallet Durability Analysis

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Light Block
Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

Pallet Service Life Analysis

The **Pallet Service Life Analysis** simulates a series of forces and impacts applied to the pallet during each handling cycle. The frequency and severity of these impacts are estimates based on laboratory measurements, warehouse observations, and the Virginia Tech FasTrack Handling Cycle. The resistance to damage and the damage level requiring component repair or replacement are based on laboratory testing and the NWPCA Uniform Standard for Wood Pallets.

Service Environment Conditions:
Average Handling and Treatment, Medium-Duty Loads, Dry Environment (EMC <= 19%)

Predicted Service Life: 12 Cycles **Predicted Cycles until First Repair:** 3

Results from Handling Cycle Simulation

Pallet Components		Cycles To First Repair	Cycles To First Replacement	Number of Times Replaced	Limits Pallet Service Life	Relative Component Damage during Simulation
Top Leadboards	(2)	5	9	1		
Top InteriorBoards	(4)		12			
Top CenterBoard	(1)		12			
Perimeter-base Outer Boards	(2)		3	3	Yes	
Perimeter-base Butted Boards	(3)		4	2		
Exterior Top StringerBoards	(2)					
Interior Top StringerBoard	(1)					
Corner Blocks	(4)					
Edge Blocks	(2)					
End Blocks	(2)					
Center Block	(1)					

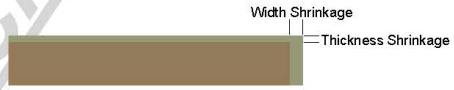
PALLET DESIGN SYSTEM Version 6.1
Pallet Physical Property Analysis

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Light Block
Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

	At Manufacture	At 25% MC	At 19% MC	At 15% MC	At 12% MC
Average Pallet Weight	68 lbs.	49 lbs.	46 lbs.	45 lbs.	44 lbs.



Dimensional Change due to Wood Drying

Component	Original Dimension	Shrinkage from Manufacture to 19% MC	Shrinkage from Manufacture to 15% MC
Top Deckboards	0.500 in. Thickness 3.500 in. Width 5.500 in. Width	0.012 in. (+/- 0.003 in.) 0.081 in. (+/- 0.023 in.) 0.128 in. (+/- 0.037 in.)	0.017 in. (+/- 0.005 in.) 0.117 in. (+/- 0.034 in.) 0.184 in. (+/- 0.053 in.)
Top Stringerboards	0.688 in. Thickness 3.500 in. Width	0.016 in. (+/- 0.005 in.) 0.081 in. (+/- 0.023 in.)	0.023 in. (+/- 0.007 in.) 0.117 in. (+/- 0.034 in.)
Blocks	3.500 in. Height 3.500 in. Width	0.081 in. (+/- 0.023 in.) 0.081 in. (+/- 0.023 in.)	0.117 in. (+/- 0.034 in.) 0.117 in. (+/- 0.034 in.)
Bottom Deckboards	0.500 in. Thickness 5.500 in. Outer Board Width 3.500 in. Butted Board Width	0.012 in. (+/- 0.003 in.) 0.128 in. (+/- 0.037 in.) 0.081 in. (+/- 0.023 in.)	0.017 in. (+/- 0.005 in.) 0.184 in. (+/- 0.053 in.) 0.117 in. (+/- 0.034 in.)

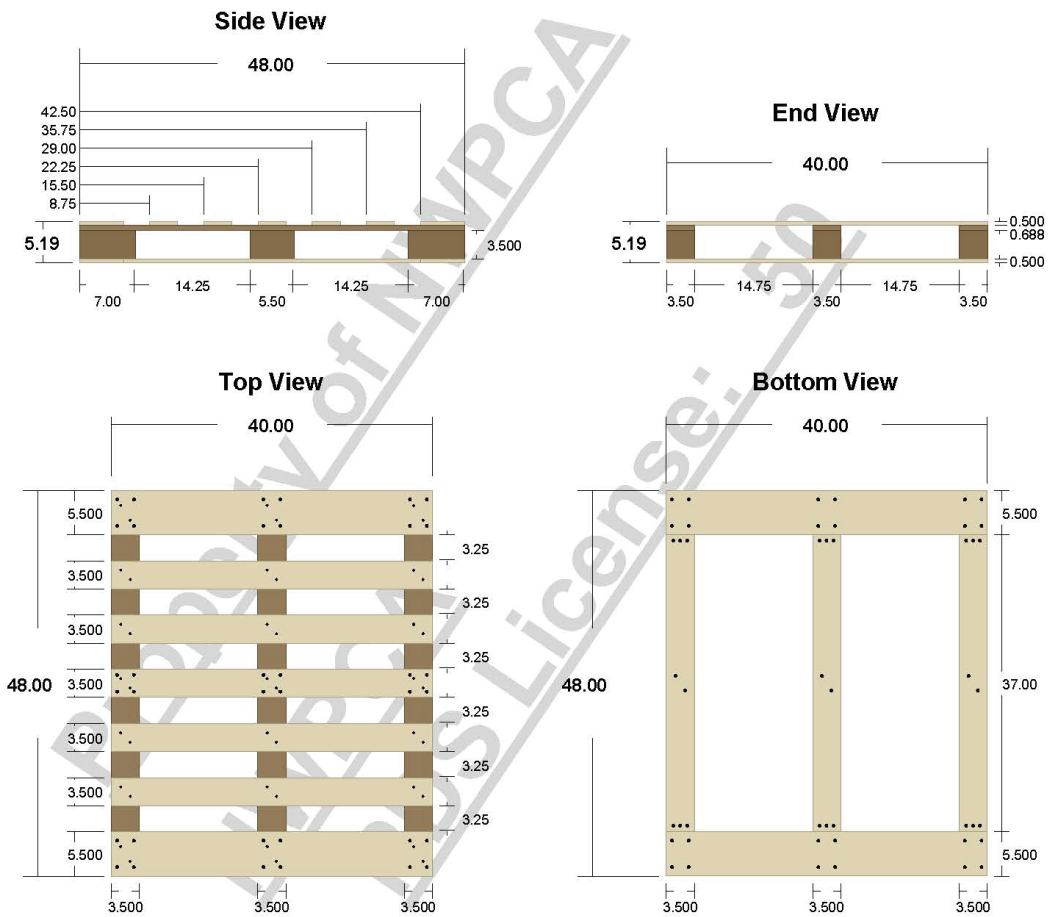
PALLET DESIGN SYSTEM Version 6.1

2-D Pallet Drawings

All dimensions in inches

Pallet ID: 48x40 Light Block

Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

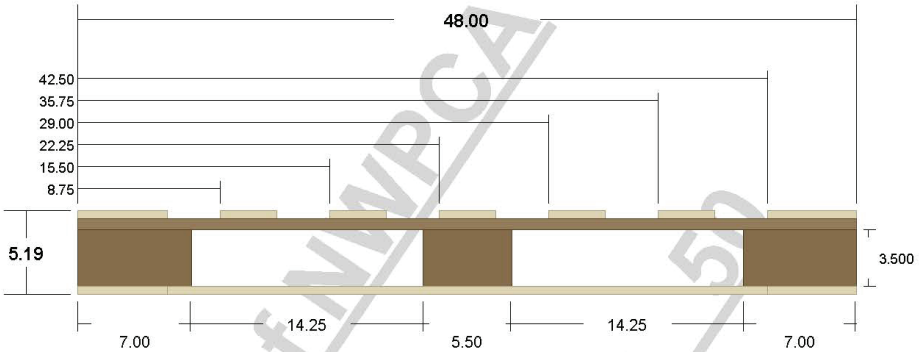
Pallet Drawing - Side and End View

All dimensions in inches

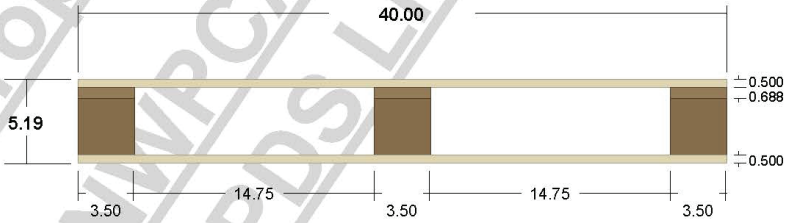
Pallet ID: 48x40 Light Block

Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

Side View



End View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

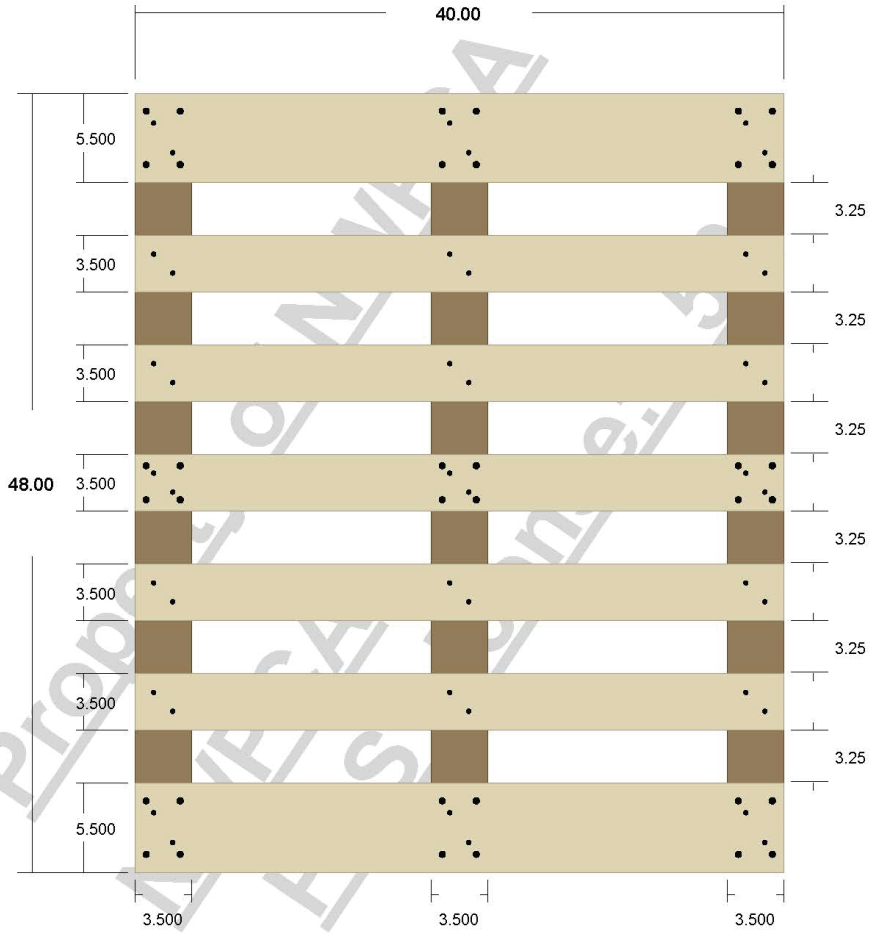
Pallet Drawing - Top View

All dimensions in inches

Pallet ID: 48x40 Light Block

Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

Top View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

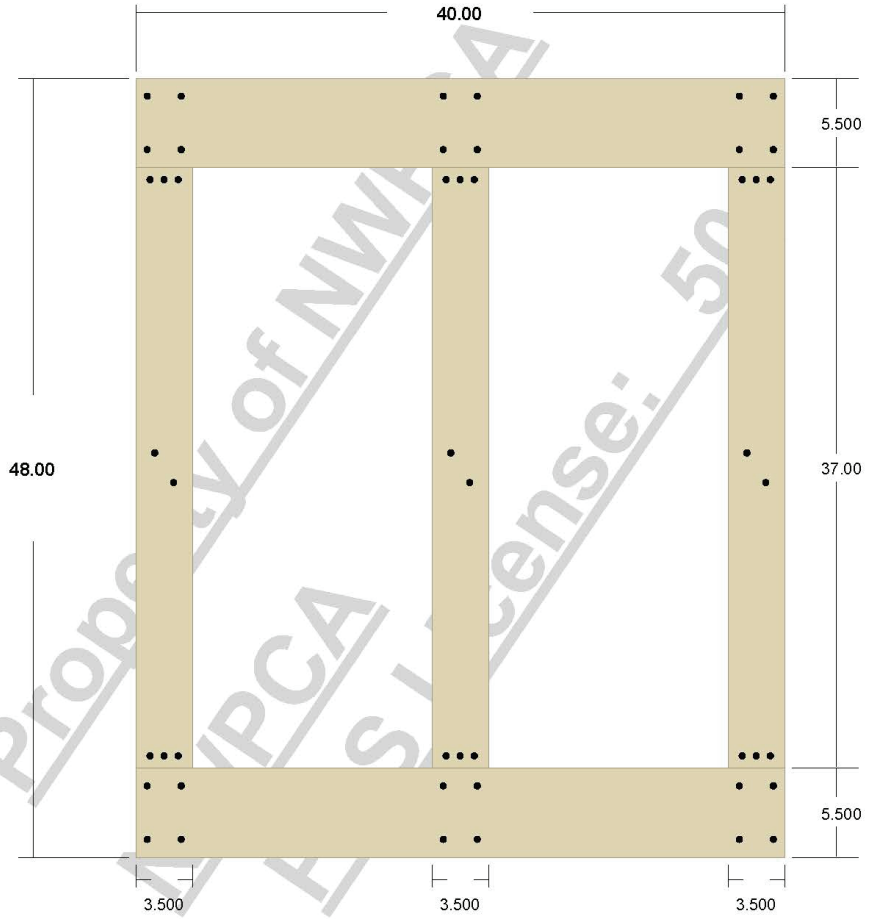
Pallet Drawing - Bottom View

All dimensions in inches

Pallet ID: 48x40 Light Block

Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

Bottom View



Customer:

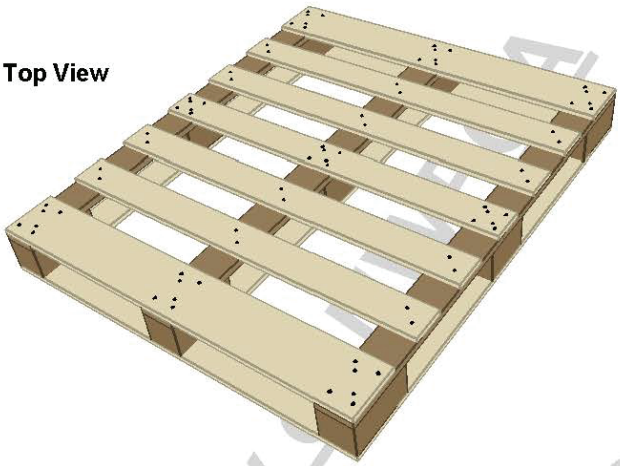
Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1
3-D Pallet Drawings

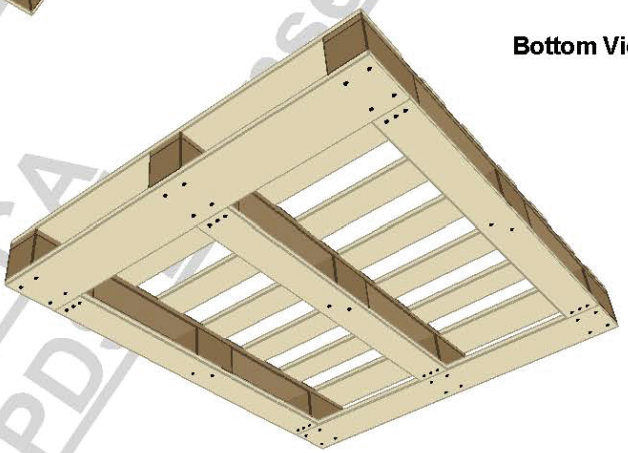
All dimensions in inches

Pallet ID: 48x40 Light Block
Classification: 48.00 x 40.00, Block-Class, Double-Face Non-Reversible, Full 4-Way, Reusable, New Manufacture

Top View



Bottom View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

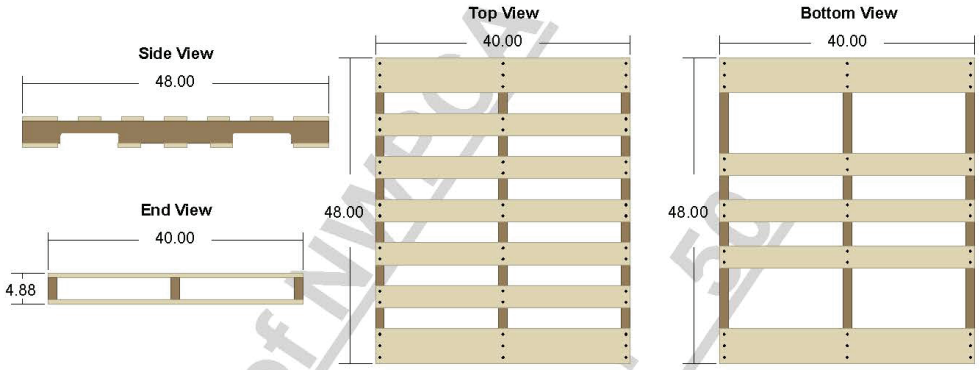
Pallet Specification Sheet

All dimensions in inches

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Heavy Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture



Components

Top Deck:

Style: Deckboard **Type:** New Lumber

Number	Thickness	Width	Length
5	0.688	3.500	40.00
2	0.688	5.500	40.00

Volume: 5.4 bd ft

Bottom Deck:

Style: Deckboard **Type:** New Lumber

Number	Thickness	Width	Length
3	0.688	3.500	40.00
2	0.688	5.500	40.00

Volume: 4.1 bd ft

Stringers:

Type: New Lumber

Number	Width	Height	Length
3	1.375	3.500	48.00

Volume: 4.8 bd ft
Partial 4-way Entry Notch:
Depth: 1.500 Length: 9.00 Location: 6.00 Radius: 0.75

Materials

Fasteners:

Fastener ID:	2-1/4 x .112 SS
Fastener Type:	Helically Threaded Nail
Fastener Length:	2.25
Thread Length:	1.25
Thread Diameter:	0.128
Wire Diameter:	0.112
Head Diameter:	0.280
Flutes:	4
Helixes:	5.4
Pitch:	0.231
Thread Angle:	66
MIBANT Angle:	36
FWC:	2.52
Total Number:	84

New Lumber:

Lumber ID:

Species Class	Grade	Lumber Mix
High Density Eastern Hardwoods	Standard &BTR	50 %
Medium Density Eastern Hardwoods	Standard &BTR	50 %

Moisture Content (at manufacture and assembly): Green

Total New Lumber Volume: 14.4 bd ft

Spec Sheet Notes:

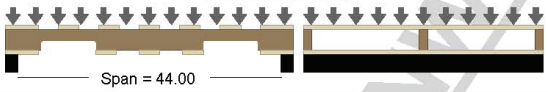
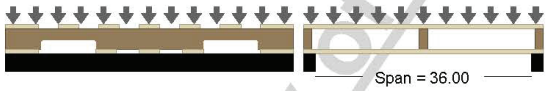
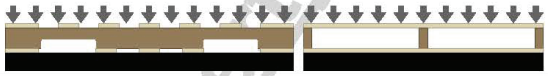
PALLET DESIGN SYSTEM Version 6.1
Pallet Structural Analysis

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Heavy Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

General Load Type: Uniformly Distributed - Full Pallet Coverage
Load Weight Variability: Medium
Service Environment: Dry Environment (EMC <= 19%)

Support Condition (Side View / End View)	Safe Maximum Load	Deflection at Maximum Load	User Specified Deflection Limit	Maximum Load for Deflection Limit	Critical Member or Connection
Racked Across Length 2 Beam Support 	1599 lbs.	0.62 in.	----	----	Center Stringer
Racked Across Width 2 Beam Support 	2093 lbs.	0.77 in.	----	----	Interior Bottom Deckboard
Warehouse Storage Stacked 1 Unit Load High 	6728 lbs.	0.24 in.	0.25 in.	NA	Interior Top Deckboard

Lateral Collapse Resistance

Pallet Design System (PDS)
Developed and owned by:
National Wooden Pallet and Container Association (NWPCA)
Research and development for early versions of PDS were conducted in cooperation with:
Center for Unit Load Design, Virginia Tech Department of Wood Science and Forest Products;
U.S.D.A. Forest Service and Forest Products Laboratory; APA - The Engineered Wood Association;
Software Technologies Laboratory, Virginia Tech Department of Industrial and Systems Engineering

PALLET DESIGN SYSTEM Version 6.1
Pallet Durability Analysis

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Heavy Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

Pallet Service Life Analysis

The **Pallet Service Life Analysis** simulates a series of forces and impacts applied to the pallet during each handling cycle. The frequency and severity of these impacts are estimates based on laboratory measurements, warehouse observations, and the Virginia Tech FasTrack Handling Cycle. The resistance to damage and the damage level requiring component repair or replacement are based on laboratory testing and the NWPCA Uniform Standard for Wood Pallets.

Service Environment Conditions:
Average Handling and Treatment, Medium-Duty Loads, Dry Environment (EMC <= 19%)

Predicted Service Life: 9 Cycles **Predicted Cycles until First Repair:** 3

Results from Handling Cycle Simulation

Pallet Components		Cycles To First Repair	Cycles To First Replacement	Number of Times Replaced	Limits Pallet Service Life	Relative Component Damage during Simulation
Top Leadboards	(2)	3	5	1	Yes	
Top InteriorBoards	(5)					
Bottom Leadboards	(2)	3	5	1	Yes	
Bottom InteriorBoards	(3)					
Exterior Stringers	(2)	5				
Interior Stringers	(1)					

PALLET DESIGN SYSTEM Version 6.1
Pallet Physical Property Analysis

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Heavy Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

	At Manufacture	At 25% MC	At 19% MC	At 15% MC	At 12% MC
Average Pallet Weight	64 lbs.	46 lbs.	44 lbs.	42 lbs.	41 lbs.

Dimensional Change due to Wood Drying

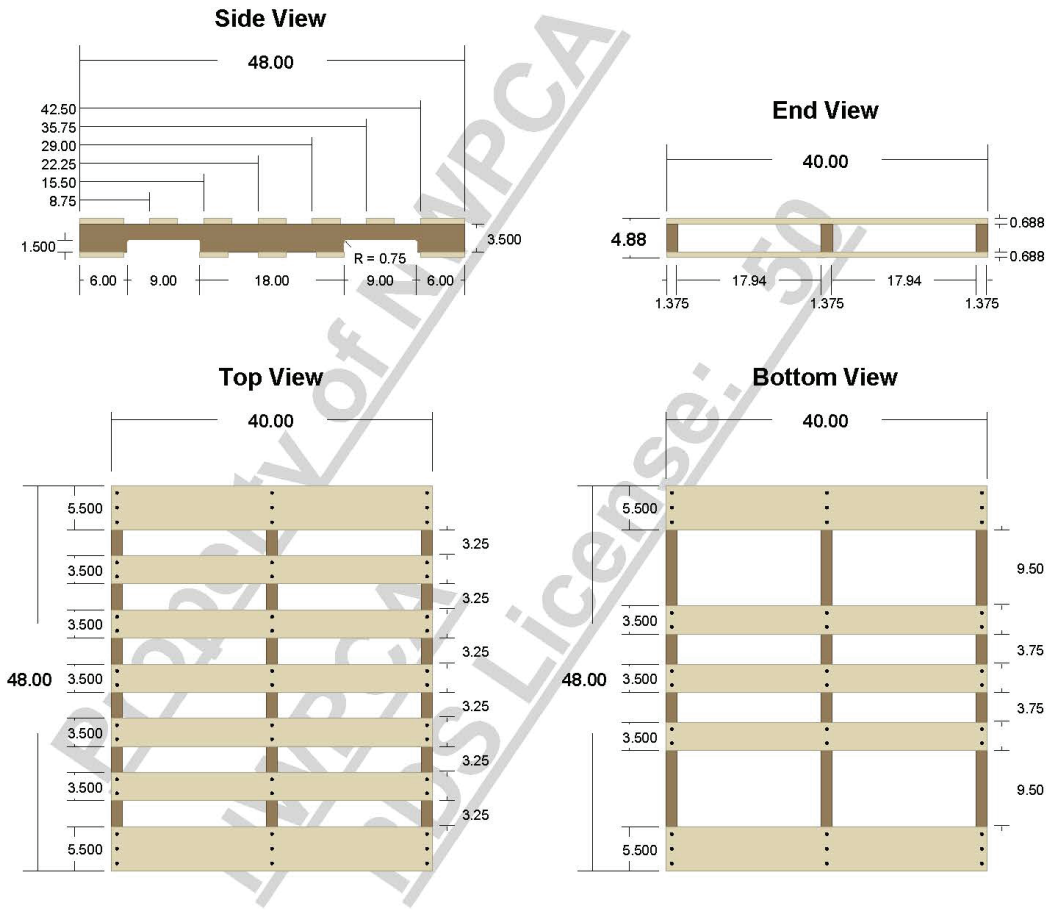
Component	Original Dimension	Shrinkage from Manufacture to 19% MC	Shrinkage from Manufacture to 15% MC
Top Deckboards	0.688 in. Thickness 3.500 in. Width 5.500 in. Width	0.016 in. (+/- 0.005 in.) 0.081 in. (+/- 0.023 in.) 0.128 in. (+/- 0.037 in.)	0.023 in. (+/- 0.007 in.) 0.117 in. (+/- 0.034 in.) 0.184 in. (+/- 0.053 in.)
Stringers	3.500 in. Height 1.375 in. Width	0.081 in. (+/- 0.023 in.) 0.032 in. (+/- 0.009 in.)	0.117 in. (+/- 0.034 in.) 0.046 in. (+/- 0.013 in.)
Bottom Deckboards	0.688 in. Thickness 3.500 in. Width 5.500 in. Width	0.016 in. (+/- 0.005 in.) 0.081 in. (+/- 0.023 in.) 0.128 in. (+/- 0.037 in.)	0.023 in. (+/- 0.007 in.) 0.117 in. (+/- 0.034 in.) 0.184 in. (+/- 0.053 in.)

PALLET DESIGN SYSTEM Version 6.1

2-D Pallet Drawings

All dimensions in inches

Pallet ID: 48x40 Heavy Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

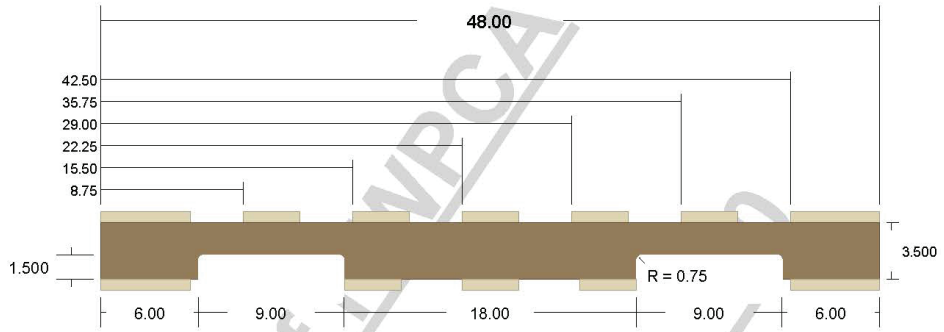
Pallet Drawing - Side and End View

All dimensions in inches

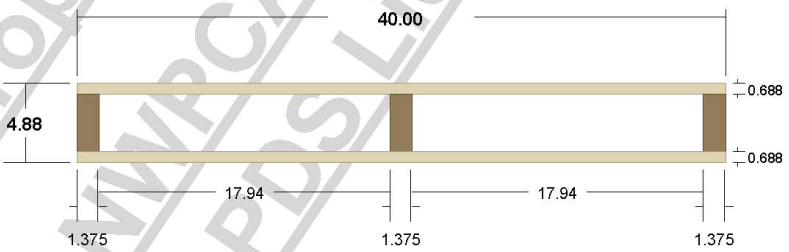
Pallet ID: 48x40 Heavy Stringer

Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

Side View



End View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

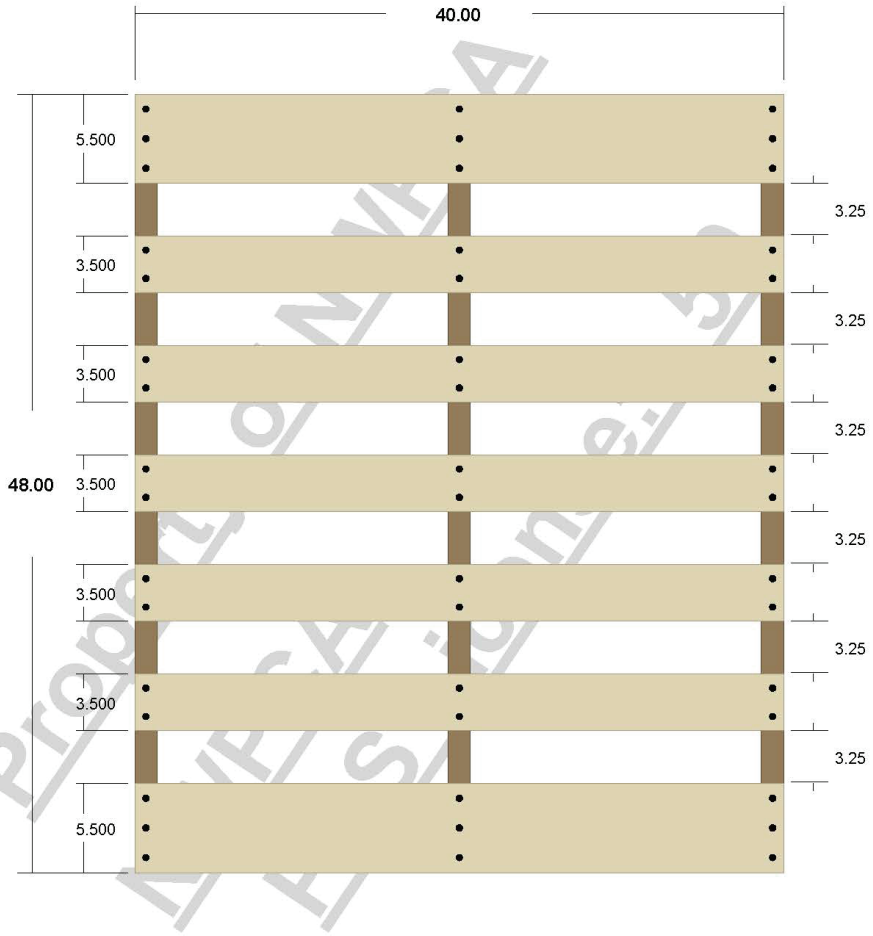
Pallet Drawing - Top View

All dimensions in inches

Pallet ID: 48x40 Heavy Stringer

Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

Top View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

PALLET DESIGN SYSTEM Version 6.1

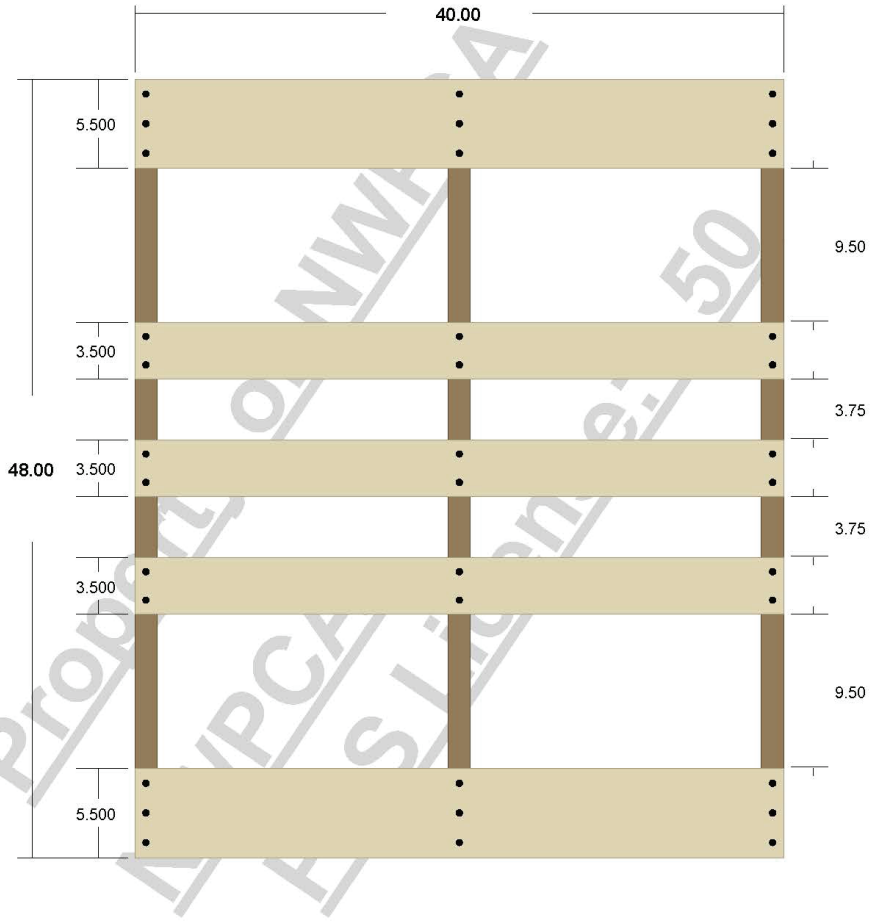
Pallet Drawing - Bottom View

All dimensions in inches

Pallet ID: 48x40 Heavy Stringer

Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

Bottom View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

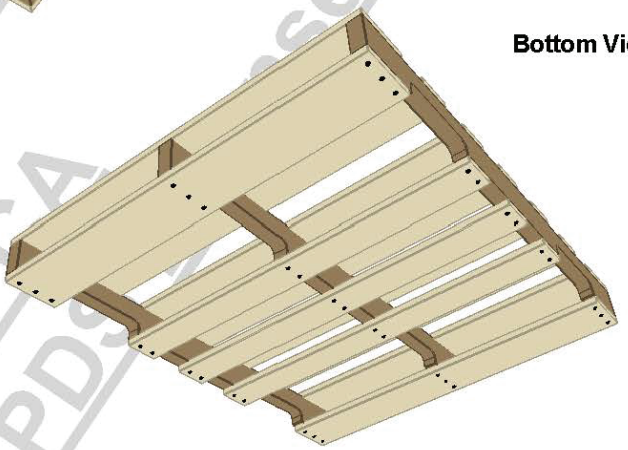
PALLET DESIGN SYSTEM Version 6.1
3-D Pallet Drawings

All dimensions in inches

Pallet ID: 48x40 Heavy Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture

Top View

Bottom View



Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

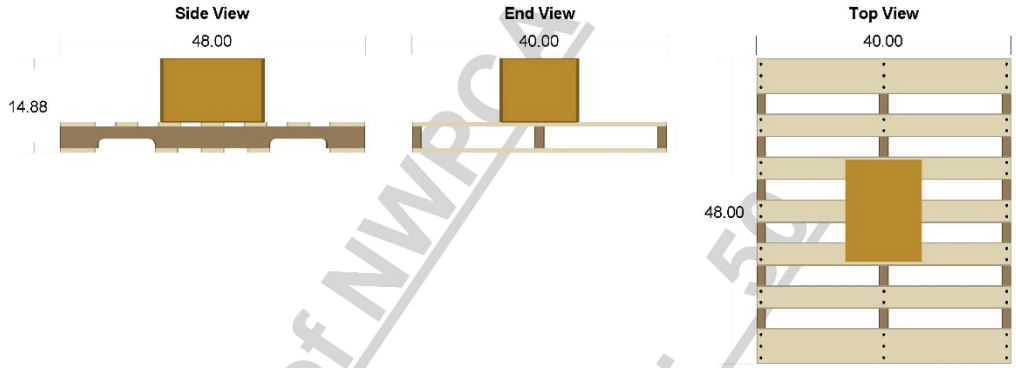
PALLET DESIGN SYSTEM Version 6.1
Unit Load Specification and Drawings

All dimensions in inches

Customer:

Prepared by:
NWPCA
PDS License: 50 Printed: March 16, 2020

Pallet ID: 48x40 Heavy Stringer
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Reusable, New Manufacture



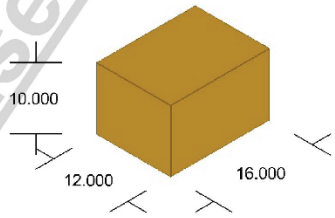
Container Type: Corrugated Box

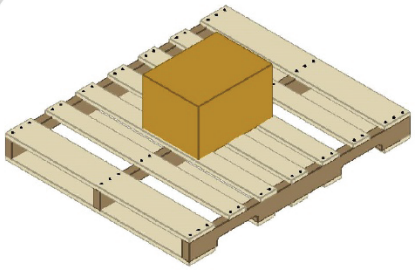
Box Style: Regular Slotted Container (RSC) #0201

Weight per Box: 20.0 lbs.

Number of Boxes per Layer: 1
Number of Layers per Unit Load: 1 **Single Stacked**
Number of Boxes per Unit Load: 1
Total Weight of Load: 20.0 lbs.
Total Height of Load: 10.000 in.

Outside Dimensions:
Length: 16.000
Width: 12.000
Depth: 10.000 *





Appendix C—Gate-to-Gate Life-Cycle Inventory per Pallet Manufactured

	Unit	Weighted average	Allocation (%)
Wood preparation and board shaping per pallet			
Products—coproducts			
Wood boards, at pallet facility	p	1.000	82.3
Sawdust	OD kg	1.448	6.8
Hogged material	OD kg	0.915	4.3
Wood chips	OD kg	1.095	5.2
Scrap wood	OD kg	0.005	0.0
Shavings	OD kg	0.291	1.4
Materials—fuels			
Wood resources, average, at pallet facility	m^3	9.21E–05	
Greases	g	1.17E–01	
Motor oil	g	3.40E–01	
Hydraulic fluid	g	7.12E–01	
Lubricating fluid	g	4.72E–01	
Plastic wrapping	g	2.99E–01	
Cardboard packaging	g	2.25E–01	
Natural gas	L	1.24E+01	
Diesel	L	3.56E–02	
Gasoline	L	3.62E–04	
Liquefied petroleum gas	L	1.63E–03	
Wood fuel	OD kg	9.22E–04	
Diesel, forklift	L	1.10E–02	
Diesel, truck	L	4.85E–03	
Gasoline, truck	L	4.93E–05	
Propane, forklift	L	3.49E–02	
Electricity—heat			
Electricity	kWh	0.734	
Waste			
Steel scrap	g	19.661	
Plastic wrap	g	0.460	
Cardboard packaging	g	5.003	
Hydraulic fluid	g	0.075	
Motor oil	g	0.011	
Greases	g	0.002	
Lubricants	g	0.981	

	Unit	Weighted average	Allocation (%)
Pallet assembly—nailing per pallet			
Products—coproducts			
Wood pallet, assembled	p	1.000	100.0
Materials—fuels			
Wood boards, at pallet facility	p	1.00E+00	
Fasteners	g	2.62E+02	
Greases	g	1.09E-01	
Motor oil	g	2.91E-01	
Hydraulic fluid	g	1.14E+00	
Lubricating fluid	g	5.04E-01	
Plastic wrapping	g	6.86E-03	
Cardboard packaging	g	6.57E-02	
Natural gas	L	5.51E+00	
Liquefied petroleum gas	L	1.63E-03	
Diesel	L	2.73E–03	
Gasoline	L	3.33E–04	
Wood fuel	OD kg	9.22E–04	
Diesel, forklift	L	1.10E–02	
Diesel, truck	L	4.85E–03	
Gasoline, truck	L	4.93E–05	
Propane, forklift	L	3.49E–02	
Electricity—heat	L	1.10E–02	
Electricity	kWh	0.327	
Waste	L	4.93E–05	
Cardboard packaging	g	1.668	
Hydraulic fluid	g	0.075	
Motor oil	g	0.011	
Greases	g	0.002	
Lubricants	g	0.981	
Treatment—stamping–painting per pallet			
Products–coproducts			
Wooden pallet final, pallet facility	p	1.000	100.0
Materials—fuels	g	0.075	
Wood pallet, assembled	p	1	
Natural gas	L	1.95E+00	
Liquefied petroleum gas	L	2.61E–02	
Fungicide	g	5.27E–02	
Paint	g	2.30E+00	
Ink	g	7.63E–04	
Electricity—heat			
Electricity	kWh	0.026	

Appendix D—Grid Mix

Grid mix for Ecoinvent 3.5 process: Electricity, low voltage {US}| market group for | Cut-off, U

Product	Value	Unit
Electricity, low voltage {US}| market group for | Cut-off, U	1	kWh
Inputs from technosphere		
Electricity, low voltage {ASCC}| market for | Cut-off, U	0.001451	kWh
Electricity, low voltage {FRCC}| market for | Cut-off, U	0.056358	kWh
Electricity, low voltage {HICC}| market for | Cut-off, U	0.002314	kWh
Electricity, low voltage {MRO, US only}| market for | Cut-off, U	0.064258	kWh
Electricity, low voltage {NPCC, US only}| market for | Cut-off, U	0.060511	kWh
Electricity, low voltage {RFC}| market for | Cut-off, U	0.241316	kWh
Electricity, low voltage {SERC}| market for | Cut-off, U	0.253861	kWh
Electricity, low voltage {SPP}| market for | Cut-off, U	0.030021	kWh
Electricity, low voltage {TRE}| market for | Cut-off, U	0.100159	kWh
Electricity, low voltage {WECC, US only}| market for | Cut-off, U	0.189751	kWh

Appendix E—Survey Questionnaire

GENERAL INFORMATION

a) Type of operation (please check all that apply):

- ☐ Pallet Production with Pre-cut Lumber only (%_____)
- ☐ Pallet production with Processing of cants or boards (%_____)
- ☐ Pallet production with Scragg mill lumber processing (%_____)
- ☐ Pallet production with Grade mill (%_____)
- ☐ Remanufacturing/ repair (Please fill out Part II Survey too if you produce remanufactured pallets)

b) Does your facility have the following?

☐ heat treatment	☐ boiler for heating and power
☐ sawmill	☐ wood-fired boiler
☐ dryers and kilns	☐ gas-fired boiler (natural or propane)
	☐ oil-fired boiler
	☐ cogeneration facility (electricity)
	☐ air pollution control device

c) Operation data:

- Total number of hours per day (all shifts): _____
- Days of operation per year: _____

  or Hours of operation per year: _____

d) Company Information:

- Company: _____
- Contact person: _____
- Contact email: _____
- Telephone: _____
- Facility Location(s): _____
- Date Prepared: _____

SECTION A: FACILITY OVERVIEW

This section contains series of tables requesting information 1) total pallet production, 2) total wood input-output.

ANNUAL NEW WOODEN PALLET PRODUCTION DATA		
Total annual new pallet production during 2018	**Amount (Count)**	**Pallet size (LxW)**
New hardwood stringer (48x40)		48x40
New softwood stringer (48x40)		48x40
New softwood block (48x40)		48x40
New hardwood block (48x40)		48x40
Other pallets total: _____		
Total number of pallets produced		

ANNUAL HEAT TREATED PALLET PRODUCTION		
	Amount	
Total board footage of pallets that have gone through heat treatment process at your facility (bf)	Actual board feet:	
	Nominal board feet:	
Total number of pallets that have gone through heat treatment process at your facility (count)		
Total board footage of pallets heat treated without going through facility's dry kiln (bf)	Actual board feet:	
	Nominal board feet:	
Total number of pallets heat treated without going through facility's dry kiln (count)		

For the first two rows, list amount of wood resource used to make pallets using either [A] actual or [B] nominal board feet values for each resource. No need to list both.

WOOD INPUTS-OUTPUTS FOR PALLET PRODUCTION							
WOOD RESOURCE USED							
	Hardwood pre-cut lumber	**Softwood pre-cut lumber**	**Hardwood lumber**	**Softwood lumber**	**Other (Specify)**	**Other (Specify)**	**Total (board feet)**
[A] Amount per resource (Actual bf)							
[A] Amount per resource (Nominal bf)							
Green (G)	%	%	%	%	%	%	
Kiln dry (KD)	%	%	%	%	%	%	
Wood species (For hardwoods: show Low Density; Medium Density; High Density by percent)							
Source/region (Pacific Northwest, Southeast, Northeast, North Central)	Please select	Please select	Please select	Please select	Please select	Please select	
Rough (Y/N)	Please select	Please select	Please select	Please select	Please select	Please select	

WOOD CO-PRODUCTS PRODUCED FROM PALLET PRODUCTION							
	Amount (tons)	**Percent moisture content (wet basis)**	**Sold as Animal Bedding**	**Sold as Mulch**	**Sold as Fuel**	**Other (please specify)**	**Waste Wood to landfill**
Sawdust		%	%	%	%	%	%
Shavings		%	%	%	%	%	%
Hogged material		%	%	%	%	%	%
Woodchips	.	%	%	%	%	%	%
Bark		%	%	%	%	%	%
Other: _____		%	%	%	%	%	%
Other: _____		%	%	%	%	%	%

SECTION B: MANUFACTURING DATA

- If specific consumption data are available as fuel consumed/pallet processed, for processes such as heat treatment, pallet assembly, etc., you can also include this data.
- Please provide estimates where data are not available.

ANNUAL ENERGY USE FOR PALLET PRODUCTION

	Unit	Amount	Wood Preparation & Board shaping	Pallet Assembly/ nailing	Heat Treatment	Painting/ Stamping	Dust Collection	Utilities (Office building, lighting, heating, and cooling)	Forklifts	On-site trucks[1]	Grinding
Natural gas	1000 ft^3		%	%	%	%	%	%	%	%	%
Propane	Gallons		%	%	%	%	%	%	%	%	%
Fuel oil	Gallons		%	%	%	%	%	%	%	%	%
Diesel	Gallons		%	%	%	%	%	%	%	%	%
Wood fuel (specify MC %)	tons		%	%	%	%	%	%	%	%	%
Diesel (for electricity)	Gallons		%	%	%	%	%	%	%	%	%
Natural gas (for electricity)	Gallons		%	%	%	%	%	%	%	%	%
Propane (for electricity)	Gallons		%	%	%	%	%	%	%	%	%
Gasoline	Gallons		%	%	%	%	%	%	%	%	%
Other:	Gallons		%	%	%	%	%	%	%	%	%

[1] **Fuel consumption for on-site trucks does not include the diesel consumption for delivery of the product to customer**

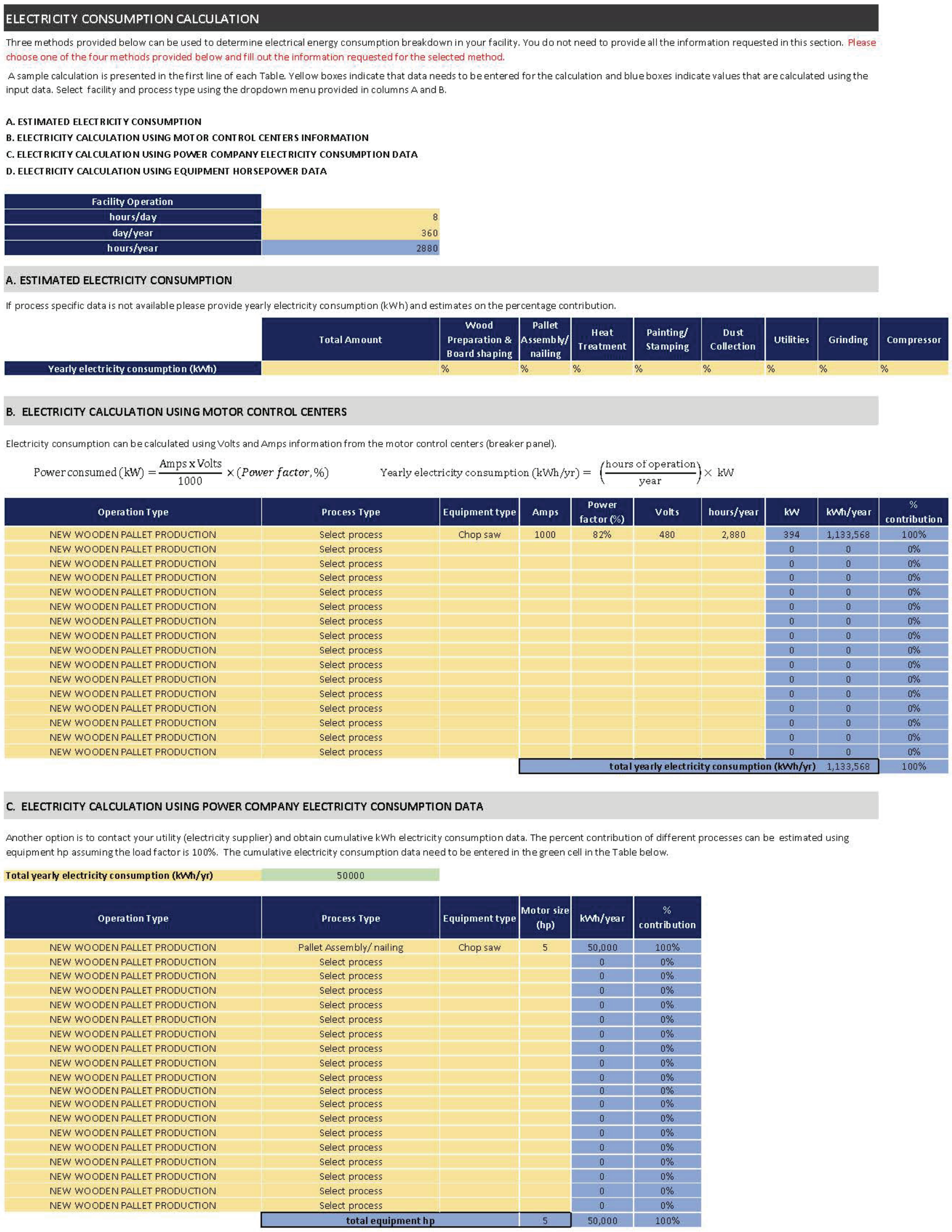
ANNUAL RAW MATERIAL TRANSPORTATION- INBOUND

		Average annual distance/ load		Number of loads per year		Average net weight of load (tons)	
Transportation	**Unit**	**Distance (truck)**	**Distance (rail)**	**truck**	**rail**	**truck**	**rail**
Hardwood pre-cut lumber	miles						
Softwood pre-cut lumber	miles						
Hardwood lumber	miles						
Softwood lumber	miles						

ANNUAL MATERIAL AND RESOURCE INPUTS FOR PALLET PRODUCTION

Ancillary Material	Used		Unit	Amount	Wood Preparation & Board shaping	Pallet Assembly/ nailing	Heat Treatment	Painting/ Stamping
	Yes	No						
Fasteners								
Staples			count					
Nails			count					
Bolts			count					
Screws			count					
Methyl bromide								
Paint			gallons					
Greases			gallons		%	%	%	%
Motor Oil			gallons		%	%	%	%
Hydraulic fluid			gallons		%	%	%	%
Lubricating fluid			gallons		%	%	%	%
Plastic wrapping			tons		%	%	%	%
Cardboard packaging (Does not include cardboard pallet)			tons		%	%	%	%
Other:					%	%	%	%
Other:					%	%	%	%
Other:					%	%	%	%

SECTION C: WASTE GENERATED					
WASTE MATERIALS					
	Amount	**Unit**	**Destination: Landfill (L), recycled (R), sewage system (S), incineration (I)**	**Other destination**	**Comments**
Steel scrap (Nails, staples, other metals)			Please select		
Plastic wrap			Please select		
Cardboard packaging waste (no cardboard pallet waste)			Please select		
Hydraulic & lubricating fluids			Please select		
Grease			Please select		
Motor oil			Please select		
Wastewater			Please select		
Other: _____			Please select		
Other: _____			Please select		



ELECTRICITY CONSUMPTION CALCULATION

Three methods provided below can be used to determine electrical energy consumption breakdown in your facility. You do not need to provide all the information requested in this section. Please choose one of the four methods provided below and fill out the information requested for the selected method.

A sample calculation is presented in the first line of each Table. Yellow boxes indicate that data needs to be entered for the calculation and blue boxes indicate values that are calculated using the input data. Select facility and process type using the dropdown menu provided in columns A and B.

A. ESTIMATED ELECTRICITY CONSUMPTION
B. ELECTRICITY CALCULATION USING MOTOR CONTROL CENTERS INFORMATION
C. ELECTRICITY CALCULATION USING POWER COMPANY ELECTRICITY CONSUMPTION DATA
D. ELECTRICITY CALCULATION USING EQUIPMENT HORSEPOWER DATA

Facility Operation	
hours/day	8
day/year	360
hours/year	2880

A. ESTIMATED ELECTRICITY CONSUMPTION

If process specific data is not available please provide yearly electricity consumption (kWh) and estimates on the percentage contribution.

	Total Amount	Wood Preparation & Board shaping	Pallet Assembly/ nailing	Heat Treatment	Painting/ Stamping	Dust Collection	Utilities	Grinding	Compressor
Yearly electricity consumption (kWh)		%	%	%	%	%	%	%	%

B. ELECTRICITY CALCULATION USING MOTOR CONTROL CENTERS

Electricity consumption can be calculated using Volts and Amps information from the motor control centers (breaker panel).

$$\text{Power consumed (kW)} = \frac{\text{Amps x Volts}}{1000} \times (\mathit{Power\ factor}, \%) \qquad \text{Yearly electricity consumption (kWh/yr)} = \left(\frac{\text{hours of operation}}{\text{year}}\right) \times \text{kW}$$

Operation Type	Process Type	Equipment type	Amps	Power factor (%)	Volts	hours/year	kW	kWh/year	% contribution
NEW WOODEN PALLET PRODUCTION	Select process	Chop saw	1000	82%	480	2,880	394	1,133,568	100%
NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
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NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
NEW WOODEN PALLET PRODUCTION	Select process						0	0	0%
			total yearly electricity consumption (kWh/yr)					1,133,568	100%

C. ELECTRICITY CALCULATION USING POWER COMPANY ELECTRICITY CONSUMPTION DATA

Another option is to contact your utility (electricity supplier) and obtain cumulative kWh electricity consumption data. The percent contribution of different processes can be estimated using equipment hp assuming the load factor is 100%. The cumulative electricity consumption data need to be entered in the green cell in the Table below.

Total yearly electricity consumption (kWh/yr)	50000

Operation Type	Process Type	Equipment type	Motor size (hp)	kWh/year	% contribution
NEW WOODEN PALLET PRODUCTION	Pallet Assembly/ nailing	Chop saw	5	50,000	100%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
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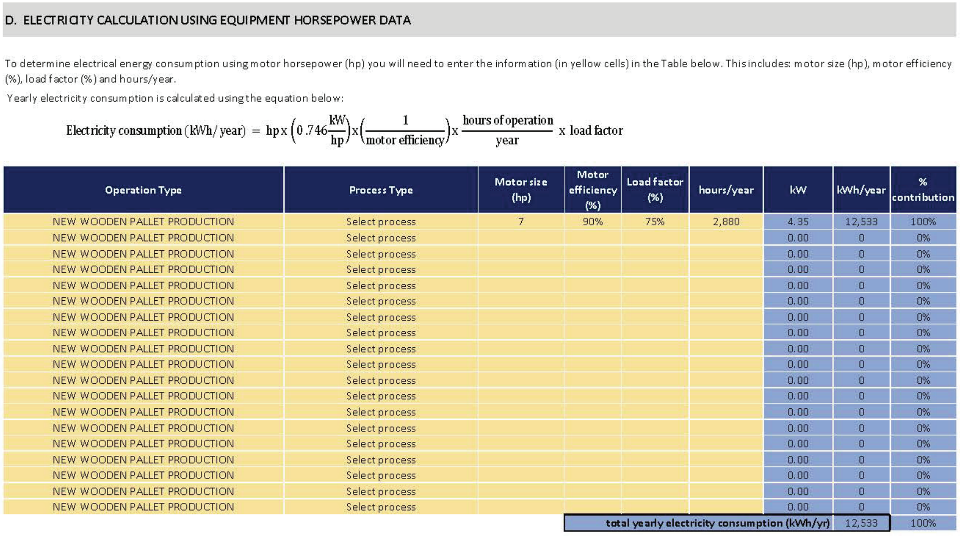
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
NEW WOODEN PALLET PRODUCTION	Select process			0	0%
	total equipment hp		5	50,000	100%



D. ELECTRICITY CALCULATION USING EQUIPMENT HORSEPOWER DATA

To determine electrical energy consumption using motor horsepower (hp) you will need to enter the information (in yellow cells) in the Table below. This includes: motor size (hp), motor efficiency (%), load factor (%) and hours/year.

Yearly electricity consumption is calculated using the equation below:

$$\text{Electricity consumption (kWh/ year)} = \text{hp} \times \left(0.746\frac{\text{kW}}{\text{hp}}\right) \times \left(\frac{1}{\text{motor efficiency}}\right) \times \frac{\text{hours of operation}}{\text{year}} \times \text{load factor}$$

Operation Type	Process Type	Motor size (hp)	Motor efficiency (%)	Load factor (%)	hours/year	kW	kWh/year	% contribution
NEW WOODEN PALLET PRODUCTION	Select process	7	90%	75%	2,880	4.35	12,533	100%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
NEW WOODEN PALLET PRODUCTION	Select process					0.00	0	0%
			total yearly electricity consumption (kWh/yr)				12,533	100%

GENERAL INFORMATION

a) Type of operation (please check all that apply):

- ☐ Repair
- ☐ Remanufacturing
- ☐ New Pallet Production (Please fill out Part I Survey too if you produce new pallets)

b) Does your facility have the following?

☐ heat treatment	☐ boiler for heating and power
☐ sawmill	☐ wood-fired boiler
☐ dryers and kilns	☐ gas-fired boiler (natural or propane)
	oil-fired boiler
	☐ cogeneration facility (electricity)
	☐ air pollution control device

c) Operation data:

- Total number of hours per day (all shifts): _____
- Days of operation per year: _____

  or Hours of operation per year: _____

d) Company Information:

- Company _____
- Contact person _____
- Contact email: _____
- Telephone: _____
- Facility Location(s): _____
- Date Prepared: _____

SECTION A: FACILITY OVERVIEW

This section contains series of tables requesting information 1) total pallet production, 2) total wood input-output.

ANNUAL REMANUFACTURED/REPAIRED WOODEN PALLET PRODUCTION DATA		
Total annual remanufactured/repaired pallet production during 2018	**Amount (Count)**	**Pallet size (LxW)**
Stringer Remanufactured/repaired(48x40)		48x40
Block Remanufactured/repaired(48x40)		48x40
Other pallets total: _____		
Total number of remanufactured/repaired pallets produced		

ANNUAL HEAT TREATED PALLET PRODUCTION		
	Amount	
Total board footage of pallets that have gone through heat treatment process at your facility (bf)	Actual board feet:	
	Nominal board feet:	
Total number of pallets that have gone through heat treatment process at your facility (count)		
Total board footage of pallets heat treated without going through facility's dry kiln (bf)	Actual board feet:	
	Nominal board feet:	
Total number of pallets heat treated without going through facility's dry kiln (count)		

For the first two rows (new lumber input), list amount of wood resource used to make pallets using either [A] actual or [B] nominal board feet values for each resource. No need to list both.

WOOD INPUTS-OUTPUTS FOR PALLET PRODUCTION							
USED PALLET INPUT	**Total (Count)**	**% reused without repair**	**% dismantled**	**% repaired**	**% Other**		
Total recycled pallet input							
% Hardwood							
% Softwood							
WOOD RESOURCE USED- NEW LUMBER INPUT ONLY							
	Hardwood pre-cut lumber	**Softwood pre-cut lumber**	**Hardwood lumber**	**Softwood lumber**	**Other (Specify)**	**Other (Specify)**	**Total (board feet)**
[A] Amount per resource (Actual bf)							
[A] Amount per resource (Nominal bf)							
Green (G)	%	%	%	%	%	%	
Kiln dry (KD)	%	%	%	%	%	%	
Wood species (For hardwoods: show Low Density; Medium Density; High Density by percent)							
Source/region (Pacific Northwest, Southeast, Northeast, North Central)	Please select	Please select	Please select	Please select	Please select	Please select	
Rough (Y/N)	Please select	Please select	Please select	Please select	Please select	Please select	

WOOD CO-PRODUCTS PRODUCED FROM PALLET PRODUCTION							
	Amount (tons)	**Percent moisture content (wet basis)**	**Sold as Animal Bedding**	**Sold as Mulch**	**Sold as Fuel**	**Other (please specify)**	**Waste Wood to landfill**
Sawdust		%	%	%	%	%	%
Shavings		%	%	%	%	%	%
Hogged material		%	%	%	%	%	%
Woodchips		%	%	%	%	%	%
Bark		%	%	%	%	%	%
Other: _____		%	%	%	%	%	%
Other: _____		%	%	%	%	%	%

SECTION B: MANUFACTURING DATA

- If specific consumption data are available as fuel consumed/ pallet processed, for processes such as heat treatment, pallet assembly, etc., you can also include this data.
- Please provide estimates where data are not available.

ANNUAL ENERGY USE FOR PALLET PRODUCTION

	Unit	Amount	Dismantle/ Board Preparation	Pallet Assembly/ Repair	Heat Treatment	Painting/ Stamping	Dust Collection	Utilities (Office building, lighting, heating, and cooling)	Forklifts	On-site trucks[1]	Grinding
Natural gas	1000 ft^3		%	%	%	%	%	%	%	%	%
Propane	Gallons		%	%	%	%	%	%	%	%	%
Fuel oil	Gallons		%	%	%	%	%	%	%	%	%
Diesel	Gallons		%	%	%	%	%	%	%	%	%
Wood fuel (specify MC%):	tons		%	%	%	%	%	%	%	%	%
Diesel (for electricity)	Gallons		%	%	%	%	%	%	%	%	%
Natural gas (for electricity)	Gallons		%	%	%	%	%	%	%	%	%
Propane (for electricity)	Gallons		%	%	%	%	%	%	%	%	%
Gasoline	Gallons		%	%	%	%	%	%	%	%	%
Other: _____	Gallons		%	%	%	%	%	%	%	%	%

[1] **Fuel consumption for on-site trucks does not include the diesel consumption for delivery of the product to customer**

ANNUAL RAW MATERIAL TRANSPORTATION- INBOUND

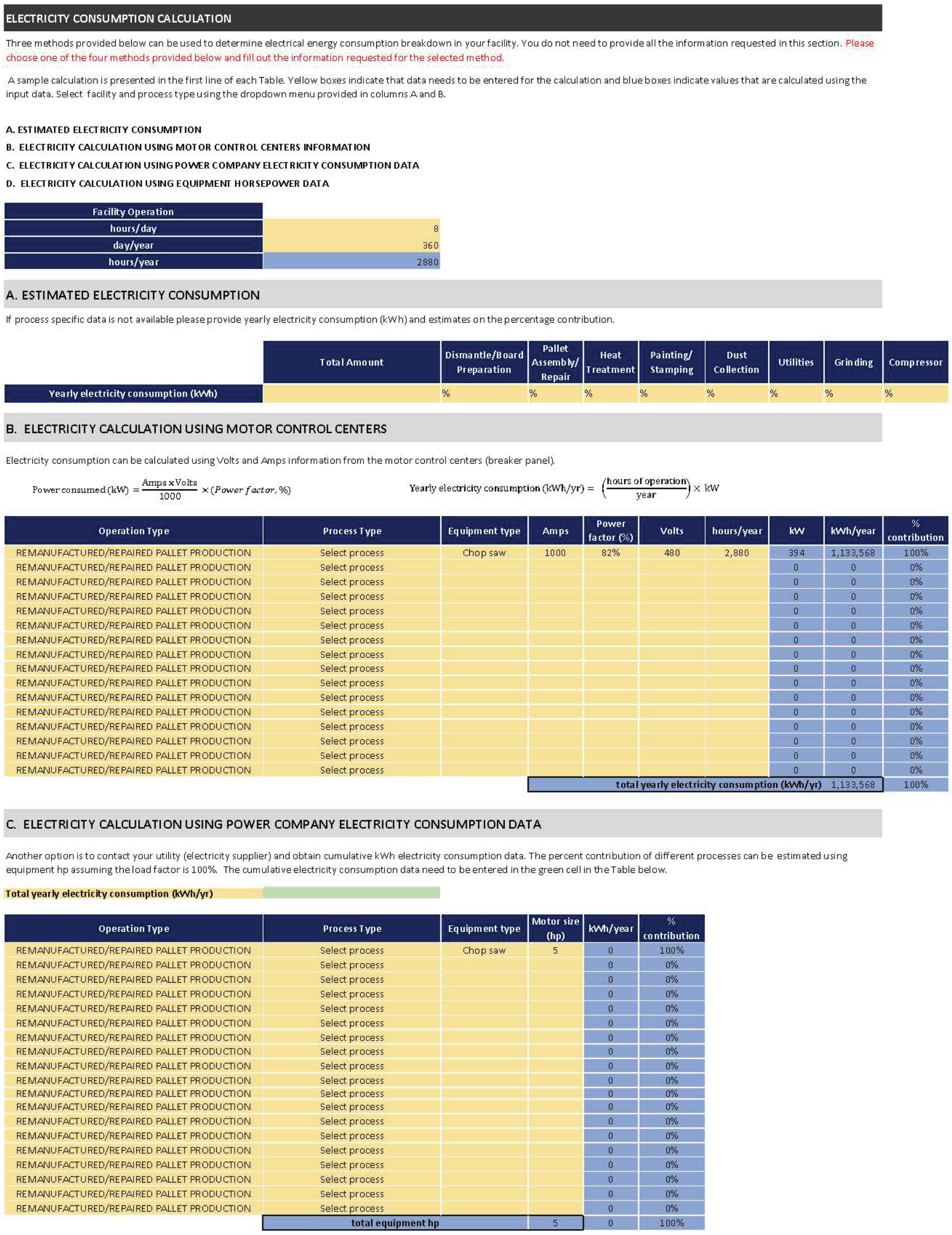
		Average annual distance/ load		Number of loads per year		Average net weight of load (tons)	
Transportation	**Unit**	**Distance (truck)**	**Distance (rail)**	**truck**	**rail**	**truck**	**rail**
How far you source your recycled pallets? (average)							
Hardwood pre-cut lumber	miles						
Softwood pre-cut lumber	miles						
Hardwood lumber	miles						
Softwood lumber	miles						

ANNUAL MATERIAL AND RESOURCE INPUTS FOR PALLET PRODUCTION

Ancillary Material	Used		Unit	Amount	Dismantle/Board Preparation	Pallet Assembly/ Repair	Heat Treatment	Painting/ Stamping
	Yes	No						
Fasteners								
Staples			count					
Nails			count					
Bolts			count					
Screws			count					
Methyl bromide								
Paint			gallons					
Greases			gallons		%	%	%	%
Motor Oil			gallons		%	%	%	%
Hydraulic fluid			gallons		%	%	%	%
Lubricating fluid			gallons		%	%	%	%
Plastic wrapping			tons		%	%	%	%
Cardboard packaging (Does not include cardboard pallet)			tons		%	%	%	%
Other: _____					%	%	%	%
Other: _____					%	%	%	%
Other: _____					%	%	%	%

SECTION C: WASTE GENERATED

WASTE MATERIALS					
	Amount	Unit	Destination: Landfill (L), recycled (R), sewage system (S), incineration (I)	Other destination	Comments
Steel scrap (Nails, staples, other metals)			Please select		
Plastic wrap			Please select		
Cardboard packaging waste (no cardboard pallet waste)			Please select		
Hydraulic & lubricating fluids			Please select		
Grease			Please select		
Motor oil			Please select		
Wastewater			Please select		
Other: _____			Please select		
Other: _____			Please select		



ELECTRICITY CONSUMPTION CALCULATION

Three methods provided below can be used to determine electrical energy consumption breakdown in your facility. You do not need to provide all the information requested in this section. Please choose one of the four methods provided below and fill out the information requested for the selected method.

A sample calculation is presented in the first line of each Table. Yellow boxes indicate that data needs to be entered for the calculation and blue boxes indicate values that are calculated using the input data. Select facility and process type using the dropdown menu provided in columns A and B.

A. ESTIMATED ELECTRICITY CONSUMPTION

B. ELECTRICITY CALCULATION USING MOTOR CONTROL CENTERS INFORMATION

C. ELECTRICITY CALCULATION USING POWER COMPANY ELECTRICITY CONSUMPTION DATA

D. ELECTRICITY CALCULATION USING EQUIPMENT HORSEPOWER DATA

Facility Operation	
hours/day	8
day/year	360
hours/year	2880

A. ESTIMATED ELECTRICITY CONSUMPTION

If process specific data is not available please provide yearly electricity consumption (kWh) and estimates on the percentage contribution.

	Total Amount	Dismantle/Board Preparation	Pallet Assembly/ Repair	Heat Treatment	Painting/ Stamping	Dust Collection	Utilities	Grinding	Compressor
Yearly electricity consumption (kWh)		%	%	%	%	%	%	%	%

B. ELECTRICITY CALCULATION USING MOTOR CONTROL CENTERS

Electricity consumption can be calculated using Volts and Amps information from the motor control centers (breaker panel).

$$\text{Power consumed (kW)} = \frac{\text{Amps x Volts}}{1000} \times (Power\ factor, \%)$$

$$\text{Yearly electricity consumption (kWh/yr)} = \left(\frac{\text{hours of operation}}{\text{year}}\right) \times \text{kW}$$

Operation Type	Process Type	Equipment type	Amps	Power factor (%)	Volts	hours/year	kW	kWh/year	% contribution
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process	Chop saw	1000	82%	480	2,880	394	1,133,568	100%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process						0	0	0%
			total yearly electricity consumption (kWh/yr)					1,133,568	100%

C. ELECTRICITY CALCULATION USING POWER COMPANY ELECTRICITY CONSUMPTION DATA

Another option is to contact your utility (electricity supplier) and obtain cumulative kWh electricity consumption data. The percent contribution of different processes can be estimated using equipment hp assuming the load factor is 100%. The cumulative electricity consumption data need to be entered in the green cell in the Table below.

Total yearly electricity consumption (kWh/yr)	

Operation Type	Process Type	Equipment type	Motor size (hp)	kWh/year	% contribution
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process	Chop saw	5	0	100%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
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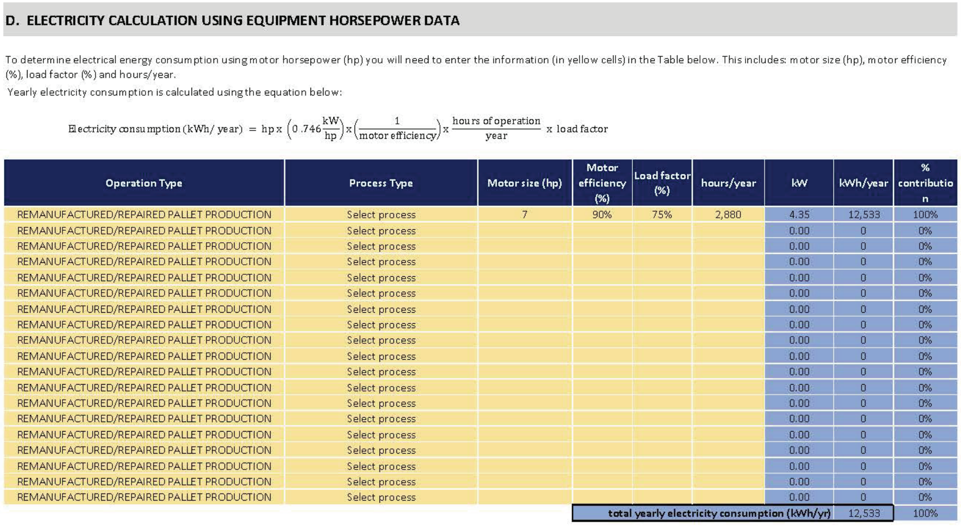
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process			0	0%
	total equipment hp		5	0	100%



D. ELECTRICITY CALCULATION USING EQUIPMENT HORSEPOWER DATA

To determine electrical energy consumption using motor horsepower (hp) you will need to enter the information (in yellow cells) in the Table below. This includes: motor size (hp), motor efficiency (%), load factor (%) and hours/year.

Yearly electricity consumption is calculated using the equation below:

$$\text{Electricity consumption (kWh/ year)} = \text{hp x} \left(0.746\frac{\text{kW}}{\text{hp}}\right) \text{x} \left(\frac{1}{\text{motor efficiency}}\right) \text{x} \; \frac{\text{hours of operation}}{\text{year}} \; \text{x load factor}$$

Operation Type	Process Type	Motor size (hp)	Motor efficiency (%)	Load factor (%)	hours/year	kW	kWh/year	% contribution
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process	7	90%	75%	2,880	4.35	12,533	100%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
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REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
REMANUFACTURED/REPAIRED PALLET PRODUCTION	Select process					0.00	0	0%
			total yearly electricity consumption (kWh/yr)				12,533	100%