Comparing energy use and environmental emissions of reinforced wood doors and steel doors

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Abstract

The USDA Forest Service Forest Products Laboratory has patented a technology that incorporates fiberglass-reinforced wood into the structure of wood doors and other wood building products. The process of reinforcing wood doors with epoxy and fiberglass increases the strength and durability of the product. Also, it allows the use of low-value, small-diameter wood which conserves mature forests and allows greater utilization of forest material. Since wood and steel are two material options for the construction of residential doors, we compared the potential environmental effects of both products (reinforced wood doors and steel doors) by conducting a partial life-cycle inventory (LCI) to compare the energy use and environmental emissions of the pre-manufacturing and manufacturing life stages of each product. The partial LCI analysis clearly showed that steel doors resulted in significantly more energy use and environmental emissions in all categories studied including air and waterborne emissions, solid waste, energy consumption, and greenhouse gas generation.

The USDA Forest Service Forest Products Laboratory (FPL) in Madison, Wisconsin, is the nation's leading wood research institute. FPL strives to develop products that conserve forest resources and are environmentally preferable. One of its recent innovations is the development of a patent that uses fiberglass reinforcement.

Localized fiberglass reinforcement provides additional support at joints and other weak points in wood products to improve the strength and durability of these products. Reinforcement in these areas provides significant enhancement to the lateral resistance of the wood. In a break-in situation, lateral resistance contributes significantly to the performance of the door. Fiberglass reinforcement also allows manufacturers to generate structurally sound products out of low-grade wood thus giving value to an otherwise low-value resource. Wood doors that are reinforced with epoxy and fiberglass are stronger and more durable than traditional wood doors and could therefore be considered a substitute for metal doors in a residential setting. In this study, we conducted a partial life-cycle inventory (LCI) to compare the energy use and environmental emissions resulting from the pre-manufacturing and manufacturing stages for both reinforced wood doors and insulated steel doors.

Partial life-cycle inventory methodology and assumptions

The energy and environmental profiles presented in this study quantify the total energy requirements, energy sources, atmospheric pollutants, waterborne pollutants, and solid waste resulting from the production of doors made with reinforced wood and steel. An LCI quantifies the energy consumption and environmental emissions for a given product based upon the study boundaries established. The partial LCI in this study focused on two stages in the life cycle of these products: 1) premanufacturing; and 2) manufacturing (i.e., from

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raw material acquisition through the door manufacturing process). A full LCI would include distribution, product use, and disposal. The methodology used for this inventory is consistent with the ISO Standards 14040 and 14041.

In order to provide a basis for comparison of different products, a common reference unit must be defined. ISO 14040 and 14041 suggest that the reference unit be based upon the function of the products, so comparisons of different products can be made on the basis of providing the same consumer utility. For this study, the functional unit is one door of the type that would typically be used for entry into a residence.

The reinforced wood door system in this study considers the wood harvested, milled, and then fabricated into a door whose finished weight is 55 pounds. According to FPL, in addition to the wood, 1 pound of fiberglass and epoxy resin is added as reinforcement; however, these materials were not included in the analysis due to the negligible effect on the results.

The steel door for this study includes 84 pounds of galvanized steel, which is produced in a basic oxygen furnace (BOF). Although the majority of steel in the United States is produced in BOFs, the use of electric arc furnaces (EAFs) for steel production has been increasing over recent years to the point of approaching half of all raw steel production. Because steel produced in an EAF has some structural limitations since scrap steel is the main feedstock, we assumed the steel for the doors assessed in this study was produced in a BOF.[1]

Steel doors for residential use have a hollow core design. Most often the core consists of some type of insulation. Therefore, the core of the steel door was assumed to be polystyrene insulation (estimated 6 lb. per door) in this analysis. The material weights associated with each functional unit are averages based on product literature from several wood and steel door manufacturers.

All life cycle energy and emissions data used in this analysis come from the Franklin Associates LCI database. This LCI database includes confidential data and data from public secondary sources. The average energy requirements for the industrial processes as well as transportation are included. Precombustion energy, which is the energy to extract, transport, and process fuels into a usable form, also is included. Environmental emissions inventoried include air pollutants, solid wastes, and waterborne wastes. These are quantified as kilograms of pollutant per unit of product output and represent actual discharges after existing pollution control devices. Industrial solid wastes inventoried include wastewater treatment sludges, solids collected in air pollution control devices, trim or waste materials from manufacturing operations that are not recycled, fuel combustion residues (e.g., ash from burning coal or wood) and mineral extraction wastes. No energy and emissions data were available for the process of adding the epoxy and fiberglass to the door. The minute amount of epoxy used to attach the fiberglass was assumed to be negligible and not included in the partial LCI. The impacts from the production of solvents and adhesives used in both systems also are considered negligible in this analysis.

Reinforced wood doors

Premanufacture

The premanufacturing process involves harvesting trees, typically softwoods (such as pines, spruces, and firs). Timber harvesting can disrupt and alter habitats. Harvesting of old-growth forests is of particular concern since these mature ecosystems are becoming more rare. In addition, soil erosion from the construction of logging roads can further disrupt local ecosystems and contribute significant sediment loadings to adjacent water bodies. Other environmental emissions include air pollutants, such as volatile organic compounds (VOCs), carbon monoxide (CO), nitrous oxides (NO_x), and particulate matter from the use of cutting and transportation equipment. Forest ecosystems also may suffer environmental damage from wood waste, damaged trees, and cutting operations. The degree of environmental harm depends largely on the harvesting practices used (EPA 1995a).

For the manufacture of reinforced wood doors, companies can use low-grade, small-diameter timber, which reduces the need to cut more mature forests and allows more of the trees in the cutting areas to be utilized thereby conserving forest resources.

Manufacture

Cut logs are brought to the sawmill where they are debarked, cut to specification, and dried in kilns. Kiln-drying can take 1 day to 1 week, depending on the type of wood and temperature of the kiln, and is a highly energy-intensive process (EPA 1995a). Kilns use a variety of energy sources, including natural gas, oil, and electricity; most, however, use on-site waste wood combustion. Once dried, the wood is cut into the pieces that will be used to assemble the door.

Energy requirements and air emissions are the primary environmental concerns related to manufacturing reinforced wood doors. Large amounts of energy are required for the kiln-drying process and for the steam and electricity to power mill equipment, such as debarking machines and saws. Much of this energy is derived from burning the waste wood, however. In fact, a typical modern sawmill produces enough waste wood to exceed its own energy requirement (DOE 1998). Boilers that burn waste wood on site may emit particulate matter, carbon monoxide, fly ash, VOCs, and other organic compounds (EPA 1998a).

Wood drying also raises concerns about off-gassing. Kilns emit approximately 2 to 5 pounds of organic chemicals per thousand board feet during the drying process. Experts estimate that up to 60,000 different organic chemicals are emitted, with only 10 percent identified. Monoturpines account for 30 to 40 percent of emissions. Other emissions include methanol, ethanol, and cyclic-hydrocarbons (Robert Rice, University of Maine, personal communication, 2000).

The manufacture of reinforced wood doors requires the application of epoxy resins and fiberglass mats to the area that surrounds the doorknob and/or the hinges. After the dried wood is cut to specification, it is run through a machine that sprays an epoxy adhesive over the identified areas. Epoxy consists of two parts, a petroleum-based resin and a hardener, which typically contains nitrogen-rich amines derived from ammonia. When mixed together, the two liquids react, forming a tight lattice of large molecular strands that eventually cures to form a permanently cross-linked poly-

[1] A sensitivity analysis was performed on the energy and solid waste of the steel door if the EAF process replaced the BOF process for the production of steel doors. Although the total energy for the steel door decreases by approximately 25 percent, the energy difference between the wood and the steel doors is still substantial. The decrease of solid waste weight for the steel door using the EAF process is significantly less than the use of the BOF process, but again is still much greater than the small amount of solid waste produced by the wood door.

mer, which in essence, is a dense, solid plastic. Fiberglass mats, which are precut to specification, are quickly pressed onto the epoxy surface before it hardens. Once the epoxy is hardened, additional layers of wood may be added to the reinforced door for aesthetic purposes.

Fiberglass reinforcement operations generate waste and air emissions during the fabrication process and from the use of solvents when cleaning tools, molds, and spraying equipment. Residual wastes include resin over-spray, partially solidified resins, unused resins that have exceeded their shelf life, fiberglass boxes, gel-coat drums, waste solvents from equipment cleanup, scrap-coated fiber, used containers, and cleanup rags. Little wastewater is generated. (EPA 1991, 1997).

Epoxies are skin and lung irritants and allergy-sensitizers. Inhalation of fumes from cured epoxy resins can cause bronchial irritation (EPA 1995e). Epoxy resins emit organic vapors, including VOCs, during the application process. VOCs are also emitted from the use of cleaning solvents, such as acetone and methylene chloride. Emissions released during spraying, mixing, brushing, and epoxy curing include styrene and other solvent VOCs.

The addition of epoxy and fiberglass to reinforced wood doors raises concerns in the manufacturing life stage because many organic and inorganic chemicals are released during epoxy manufacture. Recent advancements in adhesives research, however, have led to the development of more environmentally friendly, soy-based adhesives that could eliminate many of the concerns associated with epoxy use in reinforced wood doors (Doering 2000).

Steel doors

Premanufacture

The premanufacture of steel doors involves mining iron ore, zinc, limestone, and coal for galvanized steel manufacture, and the manufacture of the insulation (or "core") materials.

Metal mining. — Surface (or "open-pit") mining of iron ore requires extensive blasting and removal of soil, vegetation, and rock to expose the ore. Zinc is mined underground. This involves sinking a shaft to reach the main body of the zinc ore and then cutting passageways at various depths to access the ore. Once removed from the mines. iron and zinc ore are transported to steel mills (EPA 1995c). Coal can be mined on the surface or underground. Limestone is generally surface mined.

Surface mining can have severe ecological effects. The site preparation, blasting, excavation, and beneficiation (i.e., processes used to regulate the size and purity of the ore product) all produce air emissions as well as solid and liquid residues. Solid wastes from mining include overburden (waste rock, tailings, and slag) which is usually applied to the land or eventually put back in the mine. Liquid residues include petroleum wastes from trucks, acid rock drainage from tailings, and mine water (water removed from a mine to facilitate access to the ore). Air emissions include exhaust from machinery and vehicles, as well as dust from blasting and crushing operations. In addition, deforestation and habitat loss result from road and site construction, erosion, and sediment-laden runoff after removal of vegetation and blasting. Fish populations can also be impacted by water pollution from runoff. Chemicals used in high volumes to mine ore include acetylene, argon, diesel fuel, and nitrogen. Those used to mine zinc include acetylene, calcium oxide, diesel fuel, propane, and sulfur dioxide (EPA 1995c).

Steel manufacture. — In a blast furnace, iron ore, coke, limestone, and sinter are heated to produce pig iron. The pig iron is sent on as molten metal (at temperatures ranging from 2,800° to 3,000°F) to a steel-making furnace, which, for doors, is typically a BOF (EPA 1995d). Molten pig iron, flux, alloy materials, and scrap metal are heated in the BOF. Most manufacturers use at least 25 percent scrap or recycled steel in a BOF (SRI 2000).

Molten steel from the BOF is poured into molds and sent to a cold-reduction mill, where it is made into sheet metal. After the rolling processes, the sheet metal is finished and coated. Galvanizing involves depositing a thin layer of zinc on the steel surface, which protects the metal from corrosion and rusting (EPA 1995d).

The pig iron process produces slag, which is either sold as a by-product or landfilled, and residual sulfur dioxide or hydrogen sulfide. In steel making, waste outputs of the BOF include pollution control system dust and sludge that contains high concentrations of metals. Grindings from resurfacing worn rolls at the rolling mills and discarding old rolls are significant solid residues produced. Air emissions include carbon monoxide from blast furnaces, nitrogen oxides, and ozone. Liquid residues include spent pickle liquor containing hydrochloric and sulfuric acids, alkaline cleaning agents from the metal cleaning operations, and wastewater from rinse baths and coating processes (including galvanizing), which may contain zinc, lead, cadmium, or chromium. Rolling, cooling, descaling, and rinsing operations also generate wastewater.

Core materials manufacture. — Steel doors have various types of cores. Core materials provide thermal and/or sound insulation and, in some cases, added strength. The type of core material used depends on the intended use of the door. For steel doors that are potential substitutes for wood doors, the common core materials are "honeycomb" cardboard insulation, polystyrene, polyurethane, mineral wool batting, or fiberglass batting. This analysis assumes that a polystyrene core is used.

Steel door manufacture

The major processes involved in fabricating steel doors include cutting, welding, stamping, incorporating insulation materials, and applying coatings. First, rolled sheets of galvanized steel are cut and formed to specified sizes and shapes. The cut steel pieces are fused together by laser or traditional welding methods to form the door (EPA 1995b). Manufacturers use different methods to incorporate core materials into the door. Some core materials require adhesives for installation. Once assembled, the door may be stamped to provide holes for doorknobs or other attachments. Manufacturers typically spray paint and heat cure the door.

In steel door manufacturing, the cutting and forming, surface preparation, and painting processes are the main generators of wastes. Solid metal wastes associated with steel cutting and stamping are generally recycled, while other materials, such as scrap core materials, are landfilled. Cutting, forming, and surface preparation operations require the use of solvents, which release VOCs such as trichloroethane, acetone, xylene, and toluene. Liquid residues from cutting, forming, and surface preparation include waste oils, acids, alkalines, and solvent wastes. Solid wastes. such as

Table 1. — Atmospheric emissions associated with the premanufacture and manufacture of a steel door vs. a reinforced wood door.

Airborne substances for which:	Number of substances
Steel door significantly higher	31
Emissions reported for steel door but not for wood door	5
Steel door significantly lower	7
Emissions reported for wood door but not for steel door	0
No significant difference	1

Table 2. — Waterborne wastes associated with the premanufacture and manufacture of a steel door vs. a reinforced wood door.

Waterborne substances for which:	Number of substances
Steel door significantly higher	28
Emissions reported for steel door but not for wood door	4
Steel door significantly lower	0
Emissions reported for wood door but not for steel door	0
No significant difference	0

Table 3. — Total energy use associated with the premanufacture and manufacture of a steel door vs. a reinforced wood door.[a]

	Feedstock energy	Process energy	Transport energy	Total energy
	(GJ per door)			
Steel door	0.16	195	0 071	2.17
Reinforced wood door	0	0 078	0 026	0 10

[a]Total energy includes both fossil and non-fossil fuels. Petroleum and natural gas are used as feedstocks for producing the polystyrene insulation in the steel door core. This use as a feedstock removes those fuels from the pool ofresources available for energy production. In an LCI, this is called feedstock energy and, in the case of petroleum, is included as the lost heating value of crude oil.

Table 4. — Solid waste associated with the premanufacture and manufacture of a steel door vs. a reinforced wood door.

	Solid waste generated		
	Process	Fuel	Total
	(kg per door)		
Steel door	13.7	8 59	22 3
Reinforced wood door	0.027	0.49	0.5l

Table 5. — Greenhouse gases associated with the premanufacture and manufacture of a steel door vs. a reinforced wood door.[a]

Greenhouse gases	Steel door	Wood door
	(kg of carbon dioxide equivalents per door)	
Fossil carbon dioxide (1)[b]	135	5.11
Methane (23)	5.87	0.13
Nitrous oxide (296)	0.10	5.1E-03
Methylene chloride (10)	2.4E-05	1.1E-06
Carbon tetrachloride (1800)	1.6E-03	7.6E-05
Total	141	5.25

[a]Non-fossil carbon dioxide is considered to have zero GHG impacts by the U.S. EPA because these sources of carbon continually cycle in and out of the atmosphere.

'Values in parentheses are global warming potentials. These global warming potentials are multiplied by the amount of GHG produced to get carbon dioxide equivalents.

metal chips, metal-bearing cutting fluid sludges, and solvent still-bottom waste, are also produced. Paint operations also generate gaseous emissions, as well as solid and liquid wastes (EPA 1995b). Use of adhesives to secure core materials is limited and is not included in this analysis. Energy is consumed during the heat-curing process.

Results

This partial LCI analysis quantifies 44 different atmospheric emissions (including 5 greenhouse gases), 32 waterborne wastes, energy consumption, and solid waste generation associated with the premanufacturing and manufacturing stages of the life cycle. The results include both process and fuel-related emissions. **Tables 1** through **5** summarize the results.

Steel doors require more energy and produce greater amounts of environmental emissions than reinforced wood doors in the premanufacture and manufacture life stages. As shown in **Table 1,** steel doors have significantly higher air emissions for 36 of the 44 atmospheric emissions analyzed. Also, they produce significantly higher quantities of waterborne wastes in all 32 emissions included **(Table 2).** According to **Tables 3** and **4,** steel doors consume 2 1 times the amount of total energy (including both fossil and non-fossil fuels) and generate over 40 times the mass of solid waste compared to reinforced wood doors.

Greenhouse gas (GHG) emissions are isolated for analysis in **Table 5.** The result of the GHG analysis is a comparison of the kilograms of carbon dioxide equivalents released during the life cycle of steel doors and reinforced wood doors. Global warming potentials are an index for estimating relative global warming contribution due to the emission of a kilogram of a particular greenhouse gas compared to the emission of a kilogram of carbon dioxide (IPCC 2001). The global warming potentials of each emission are shown in parentheses in **Table 5.** In the premanufacturing and manufacturing stages, steel doors are estimated to produce 27 times the carbon dioxide equivalents produced during the same stages for the reinforced wood doors.

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