Life Cycle Assessment (LCA) is becoming an increasingly important methodology for assessing building materials. It is particularly useful for understanding the production-related impacts of materials, as well as the potential trade-offs between life cycle stages.

This analysis of a brick bearing wall is both quantitative (tracking a series of economic, environmental, and ethical metrics across all life cycle stages) and qualitative (describing each life cycle stage and its impacts). In order to make this LCA as specific as possible, Longworth Hall in Cincinnati, Ohio, is used as a point of departure; however, industry-wide data also has been tracked whenever possible. Although Longworth Hall was constructed in 1904, present-day data has been used—effectively calculating the impacts of building Longworth Hall today.

Because of brick's durability, the costs and benefits of a brick wall are incurred over a long period of time and over many life cycle stages, making it difficult to assess through traditional means. LCA is uniquely poised to clarify these costs and benefits. Perhaps more fundamentally, the author was curious about the sustainability of brick. Conventional wisdom holds that bearing walls are impractically expensive and have high embodied energy. But brick is also extremely durable, as well as beautiful, and its construction celebrates craftsmanship and human labor. This assessment, therefore, was in part a test of conventional wisdom.

Longworth Hall, also known as B & O Freight Terminal, is a brick masonry structure built in 1904. At 1,277 feet in length and five stories high, it is one of the largest buildings of its kind. It is listed on the National Registry of Historic Places, and is currently used as an office building. It was selected because of the author's personal fondness for the building, and because it embodies the qualities of durability, flexibility, and beauty.

As with all LCAs, this analysis is limited by the availability of information. The author has tried to make the assessment as transparent as possible, highlighting assumptions and gaps in data. The results are also compared to EIOLCA, an existing LCA tool. Comments and questions are appreciated and welcomed.
This analysis looks at the economic, environmental, and ethical impacts of the life cycle of a brick bearing wall—from the extraction of raw materials through the end of its useful life. Mapped here are the major materials and points of transportation included in the lifecycle of a brick wall. Also included are three potential end of life pathways: reuse, downcycling, and landfiling. Not included in this diagram is the supply chain of power generation (e.g., the total supply chain for electricity used in brick manufacturing). Also absent are the “accessories” of a brick bearing wall: metal coping, flashing, etc., as well as the supply chain of the equipment and tools required for manufacturing and construction (e.g., mixers, scaffolding, trowel, etc.).
This analysis focuses primarily on clay. A brick bearing wall is composed of 71% brick by volume. Brick, in turn, is composed of 80-85% clay. Clay therefore accounts for 57-60% of a brick bearing wall by volume. A more complete Life Cycle Assessment, however, would include all of the constituents shown on the prior page. In addition, this analysis assumes downcycling as the end of life pathway, both because it is common practice and because data is readily available. It further assumes that all transportation is by truck (also common practice). Finally, this analysis tracks six quantitative metrics through all lifecycle stages: cost, greenhouse gas (GHG) emissions, water use, injury / illness rate, fatality rate, and mean annual wage.

Carl S. Sterner
October 2010
In general, common clay consumed domestically is produced domestically. Imports and exports of common clay are not significant; the U.S. Geological Survey does not track common clay as its own category. According to Calkins (2010), clay quarries are typically “located adjacent to or within a few miles of the brick manufacturing facility […].” Research suggests that quarries are often owned and operated by the same companies that manufacture the brick. In 2008, the top four states producing clay for use in brick production were, in descending order, North Carolina, Georgia, Alabama, and Texas, which together accounted for 40% of production.

In states that account for a high percentage of domestic clay production, mining often plays a significant role in the local economy. In North Carolina, for instance, brick manufacturing is the third largest mining industry, and the annual production value of common clay is $12.9 million.

The primary environmental impacts of clay mining are: land and habitat disturbance; soil erosion; and increasing turbidity of local waterways. However, clay mines are not as deep as other types of mines; former clay mines are often reclaimed and the end of their useful lives; and clay mining produces far less waste than other types of mining.

Mining also comes with energy and water use, and emissions to air and water. Emissions to air are primarily from the combustion of fossil fuels. Data for clay mines was unavailable. Limestone mining was used as a proxy, which produces 5.11E-05 kg emissions per kg; clay likely emits less given the processes involved.

Water is used both for controlling dust at mines and for processing clay prior to shipping (which can include slurring). Dust control measures use about 1-6 gallons of water per ton. Processing varies depending upon end use, but a rough figure is ~2,000 gallons per ton of finished product. It is not clear whether this water is reused.

Mining is a high-risk occupation, with an average fatality rate of 12.7 per 100,000 workers per year (384.8% of the average of 3.3 across all sectors). This figure is likely lower for clay mining because the mines are relatively shallow and the material does not have to be blasted. The average injury / illness rate for mining is 3.4 per 100 employees—91.9% of the average of 3.78 across all sectors. Dust and particulates from clay mining can pose a risk if inhaled.

Miners appear to be paid a fair wage. In the Cincinnati area, the average salary is $41,922—99% of the local average salary. However, the wages are not proportional to the risk, suggesting that the occupation is at least somewhat exploitative.

2. Calkins, Materials for Sustainable Sites, 181.
3. For example, brick manufacturers Pine Hall Brick Company, Hanson Brick East, and General Shale Brick together account for more than half of the clay mines in North Carolina (the largest clay-producing state). See NC Dept. of Environment and Natural Resources, “Permitted Mines in North Carolina.”
5. NCGS, “Mineral Resources.”
7. Calkins, Materials for Sustainable Sites, 182.
8. NREL, U.S. Life-Cycle Inventory Database, “Limestone, at mine.”
12. See Appendix A for calculations & sources.
The economic and environmental portions of the manufacturing analysis utilize data from the Department of Energy’s Industrial Technologies Program (ITP), which (among other things) performs assessments of manufacturing facilities and makes suggestions for efficiency improvements. This analysis averages data from three facility assessments completed in 2010.1

Greater accuracy could be achieved by (1) including a larger number of assessments, and/or (2) using a weighted average where appropriate. (For example, revenue per unit varied widely across the three facilities, and appeared to correlate with total output—i.e., those facilities with higher output had a far lower per unit revenue.) Finally, it is not clear that the facilities assessed by ITP are representative of brick manufacturing facilities as a whole—there may be self-selection effects or other biases. Comparisons with other data sets could help to answer this question.

Brick production is incredibly energy-intensive. Brick kilns are typically heated to 350-400 degree Fahrenheit, and are normally powered by natural gas.2 In the three facilities studied, the manufacturing process consumed an average of 3,776 Btu per brick, of which 78% was natural gas and 22% was electricity.3 This translates to 1.67 MMBtu per ton of bricks.4

Greenhouse gas emissions averaged 786.07 lbs CO₂e per ton brick, of which electricity production was responsible for 633.53 lbs and natural gas was responsible for 152.54 lbs.5 Despite only accounting for 22% of energy use, electricity production accounts for nearly 81% of emissions. This discrepancy warrants further investigation.

One explanation could be that electricity generation in Ohio is primarily coal-fired, which is far dirtier than natural gas.

The three manufacturing facilities sampled took in anywhere between $0.05 and $0.52 per unit brick; this wide variance warrants further investigation.6

Brick manufacturing has a high injury / illness rate, a relatively low fatality rate, and appears to pay a below-average salary. It therefore appears to be at least slightly exploitative based upon wages and risk. Given high injury and illness rates, health coverage for workers is an important factor in this equation, but has not been evaluated here.

In Cincinnati, brick manufacturing employees earn approximately 75% of the local average wage across all industries, but 96% of the local median wage across all industries.9

1. U.S. DOE, Industrial Assessment Centers Database (assessments UA0022, NC0352, and CO0578).
4. For calculations, see Appendix A.
6. U.S. DOE, Industrial Assessment Centers Database.
Although Longworth Hall was built in 1904, the figures below reflect present-day (2010) costs—what it would cost if Longworth Hall were constructed today.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost per s.f. wall</th>
<th>Cost per ton brick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare material cost (brick &amp; mortar, including waste)</td>
<td>$2.90</td>
<td>$123.82</td>
</tr>
<tr>
<td>Labor cost</td>
<td>$6.08</td>
<td>$259.60</td>
</tr>
<tr>
<td>Total bare cost</td>
<td>$8.98</td>
<td>$383.42</td>
</tr>
<tr>
<td>Total cost (including overhead &amp; profit)</td>
<td>$12.34</td>
<td>$526.88</td>
</tr>
</tbody>
</table>

While the material itself is relatively inexpensive, the labor costs make this type of construction relatively expensive, as a team of skilled brickmasons are required. However, this expense can be viewed as spending money on jobs and a long-lasting material.

The actual construction of a brick bearing wall incurs little environmental impact. Waste is minimal, and little equipment is required. The waste factor for bricks is 5% and 25% for mortar. Construction wastes are often landfilled, although brick waste can also be recycled or reused (see “End of Life” for more).

While the material itself is relatively inexpensive, the labor costs make this type of construction relatively expensive, as a team of skilled brickmasons are required. However, this expense can be viewed as spending money on jobs and a long-lasting material.

Bricks are installed by a team consisting of (3) bricklayers and (2) bricklayer helpers. According to the U.S. Department of Labor Statistics, Brickmasons in Cincinnati earn approximately $50,110 annually—118% of the local average of $42,340. The illness / injury rate is 4.6 cases per 100 employees (124.3% of the average across all industries), and fatality rates are 18.3 per 100,000 employees (554.5% of average). Fatality data is for all “construction workers”; it is assumed that this figure is representative of bricklayers.

According to Calkins (2009), health risks for bricklayers are relatively minimal: dust from cutting bricks can irritate lungs and eyes, and prolonged exposure can cause serious respiratory problems. These risks, however, can largely be avoided by using proper protection. Though the compensation is good, the high injury and fatality rates make the job at least slightly exploitative. As with other life cycle stages, health benefits are an important factor that have not been explored here.

2. Calculated. For calculations, see Appendix A.
7. U.S. BLS, “2009 CFOI.”
8. Calkins, Materials for Sustainable Sites, 186; citing others (ATSDR 2003b, and Demkin 1999b).
In general, brick bearing walls are very durable and require little maintenance. Most maintenance is preventative: checking for hairline cracks, deterioration of mortar, plant growth on the wall, or other factors that could signal problems or lead to eventual damage. Non-brick components (such as coping) need to be replaced at the end of their lifespan.

Perhaps the most arduous task is repointing—the process of replacing mortar that has deteriorated and/or reached the end of its useful life. Repointing is typically required every 25 to 50 years. Mortar is removed to a uniform depth, and new mortar is applied. Like the construction of a brick wall, repointing is labor-intensive and requires skilled craftsmen. As a result, it bears similar liabilities, and has similar environmental and ethical merits, as brick construction.

Damaged bricks may occasionally need to be replaced. Like repointing, this requires a skilled craftsman, but requires little in the way of materials.

While brick has a high embodied energy, it is an extremely durable material, particularly when used in a bearing wall application. According to Joseph Lstiburek of the Building Science Corporation, brick has an expected lifespan of 100 years or more. Longworth Hall, built in 1904, is 106 years old at the time of this writing, and will likely be in service for at least several more decades. This gives brick an advantage when compared to other, less durable, materials. As Lstiburek notes, “If you double the life of a building and you use the same amount of resources to construct it, the building is twice as resource efficient. Therefore durability is a key component of sustainability.”

However, not all of the components of a brick wall have the same lifespan. Metal coping and flashing lasts 25 to 75 years; mortar lasts 25 to 50 years; and some more modern additions to brick walls, such as sealants and brick ties, only last 5 to 20 years. In many cases, the lifespan of the assembly is limited by the lifespan of the least durable component.

Because this analysis is focused on a material, brick, rather than a building, the energy used for building operation is beyond its scope. Operating energy is, however, significant over the life of a building. In some contexts, brick may contribute to the energy performance of a building through its thermal mass effects. Brick, like concrete, stone, and other massive materials, is highly effective at storing heat energy. This “thermal lag” can mitigate diurnal temperature swings, and can be used to capture and store solar heat energy in winter months.

Longworth Hall is uninsulated, and Cincinnati’s weather covers a large range between hot and cold. As a result, the contribution of brick to the performance of the building is unclear, and requires further investigation. A more robust life cycle assessment would take building operation into account in an effort to understand trade-offs between lifecycle phases. 

2. Ibid.
4. Ibid.
6. A 2009 study of historic buildings by the Athena Sustainable Materials Institute found that, properly renovated, historic structures could perform as well as (or even better than) new buildings. They attribute this in part to thermal mass benefits and low window-to-wall ratios. Athena Sustainable Materials Institute, “A Life Cycle Assessment Study of Embodied Effects for Existing Historic Buildings.”
LANDFILL

The nearest construction and demolition waste (C&D) landfill to Longworth Hall is H. Hafner & Sons, Inc., which provides both landfilling and recycling services. This facility was used for landfilling and recycling data. Further research is needed to understand whether this case is representative of C&D landfills in general.

H. Hafner & Sons charges for construction waste by the container. Price depends on whether the container contains “clean fill, brush, construction / demolition debris,” or “solid / sanitary waste.” The former is substantially cheaper: $325 vs. $500, respectively, for a 20-yard container.\(^1\) Presumably this is due to the economic advantage of clean debris, which can be recycled into salable products.

“Solid waste landfills” have an injury / illness rate 148.6% above the average across all industries,\(^2\) and a fatality rate 763.6% above the average.\(^3\) However, the mean annual wages for “waste treatment and disposal” were only 88% of the average salary in Ohio.\(^4\) As a result, landfills appear to be at least moderately exploitative.

RECYCLING

H. Hafner & Sons downcycles approximately 65% of its daily infeed into landscape supplies such as gravel, aggregate, and mulch. According to Justin Cooper, operations manager, “From the landfill, we receive all of the materials that we need to support our landscape material supply business.” Non-treated wood is ground for mulch; cardboard is composted with yard waste; concrete and brick are crushed for recycled aggregate; and metals are sorted and sold for scrap. While recycling confers an economic advantage, its environmental impacts are unclear—particularly since it is being downcycled into a lower-grade material rather than being truly recycled.

Separate ethical indicators for recycling services are not available from the Bureau of Labor Statistics. More fine-grained information is needed to determine whether recycling facilities differ markedly from other waste facilities.

REUSE

Brick walls can be “deconstructed” rather than “demolished.” This allows the material to be reused as brick, rather than downcycled.

There are several resources for building reuse in Cincinnati. Building Value is a building re-use store that accepts brick for reuse. In addition, Building Value provides “on-the-job training […] to move people with workforce disadvantages into construction and retail careers.”\(^5\) Similarly, Covington Reuse Center accepts brick, and hires and trains people with “workplace disadvantages.”\(^6\) Both provide building deconstruction services, as well as storing and selling salvaged materials.

Building deconstruction is much more labor-intensive (and therefore expensive) than demolition; however, because reuse operations tend to use a non-profit model, the precise cost difference is difficult to ascertain. While no figures are available regarding illness / injury / fatality rates, the explicit social mission of many building reuse operations suggests strong ethical performance.

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\(^{1}\) H. Hafner & Sons, Inc., “Cincinnati Dumpster Rental.”
\(^{2}\) U.S. BLS, “Incidence Rates of Nonfatal Occupational Injuries and Illnesses, 2008.”
\(^{3}\) U.S. BLS, “2009 CFOI.”
\(^{5}\) Quarry News, “Cincinnati Recycler Prefers Keestrack Destroyer.”
\(^{6}\) Building Value, “Job Training.”
\(^{7}\) Covington Re-Use Center website.
Transportation figures are based upon Longworth Hall in Cincinnati, Ohio. Research indicates that these figures are slightly below average, but not atypical.

### TRANSPORTATION DATA

<table>
<thead>
<tr>
<th>Transportation</th>
<th>Distance (miles)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction to manufacture</td>
<td>0</td>
<td>Quarry is co-located with brick plant. Research indicates this is not atypical.</td>
</tr>
<tr>
<td>Manufacture (1) to assembly (2)</td>
<td>123</td>
<td>From Hanson Brick (Staunton, KY) to Longworth Hall. 70% of metropolitan areas are within 200 miles of a brick manufacturing facility.</td>
</tr>
<tr>
<td>Assembly (2) to disposal (3)</td>
<td>10.6</td>
<td>From Longworth Hall to H. Hafner &amp; Sons recycling / C&amp;D Landfill</td>
</tr>
<tr>
<td>TOTAL</td>
<td>133.6</td>
<td>Cradle-to-grave</td>
</tr>
</tbody>
</table>

### ENVIRONMENTAL

Assuming emissions of 22.2 lbs of CO₂ per gallon of diesel fuel burned, an average fuel efficiency of 6 mpg for large trucks, and an average load of 12 pallets of brick per truck, the transportation of brick for Longworth Hall emits 37.88 lbs of CO₂ per ton of bricks. The majority of this is from the point of manufacture to the point of assembly, which accounts for 92% of the transportation and associated emissions. Using industry-average data (rather than Longworth Hall-specific figures) yields slightly higher values: 75.13 lbs of CO₂ per ton of bricks, of which 75% is from manufacture to point of assembly.

Bricks tend to be shipped on wood pallets. Approximately 50% of these are recovered and reused. Some companies have found ways to ship bricks without pallets. In addition, some manufacturers are experimenting with incorporating sawdust or other fillers into bricks, which yields a lighter product that requires less energy to ship. However, a full LCA would be required to ascertain the overall performance of these alternatives.

### ECONOMIC & ETHICAL

According to the "price estimator" on the website UShip, the shipping costs for brick are likely in the range of $65.00 per ton. The relatively short distances between life cycle stages means relatively low shipping costs; however, the weight of brick (a single pallet is about 1.5 tons) certainly counts against it.

Truck drivers have very high rates of injury and illness, and are among the occupations with the highest fatality rates. The injury rate for truck drivers is 5.5 per 100 full-time employees, 148.6% higher than the average of 3.7 across all industries. The fatality rate is 18.3 per 100,000 employees per year, 555% higher than the average of 3.3 across all industries.

The median annual wages for a truck driver in Ohio are $37,770, 114.5% above the median of $32,950 across all occupations. Mean annual wages are $39,260, 92.7% of the mean across all occupations. Even so, the wages are not proportional to the increased risks of injury and/or death.

1. Brick Industry Association, "Sustainability and Brick."
3. Hanson Brick and Tile, "Sustainable Development."
5. UShip website, Price Estimator.
7. U.S. BLS, “2009 CFOS.”
increasing the multiplier effect—the impact of a dollar spent. Buying local can help strengthen a local economy by finally, clay is produced domestically, often within 200 miles of a project site. Equipment is largely people-powered, is reused when construction is over, and is not associated with any on-site emissions (with the possible exception of equipment for mixing mortar, which have not been quantified here).

The construction of a brick bearing wall is by far the most expensive stage of its life cycle. Brick is labor-intensive, requiring a team of skilled brickmasons to assemble the structure by hand.

From an economic perspective, brick is a costly material. But from an ethical and environmental perspective, paying for human labor (as opposed to paying for energy or material use) is perhaps the more sustainable option. Brickmasons are well-paid (see next page), and construction comes with relatively few environmental costs. Equipment is largely people-powered, is reused when construction is over, and is not associated with any on-site emissions (with the possible exception of equipment for mixing mortar, which have not been quantified here).

Finally, clay is produced domestically, often within 200 miles of a project site. Buying local can help strengthen a local economy by increasing the multiplier effect—the impact of a dollar spent.

The manufacturing of brick is an energy-intensive process typically powered by natural gas. Brick kilns heat the brick to 350-400 degrees Fahrenheit (and sometimes as high as 2000 degrees F). Transportation figures are relatively low (824 lbs CO2-e per ton over the entire life cycle). Clay extraction is often co-located with brick manufacturing facilities, which in turn are typically within 200 miles of a project site. Not considered here are the impacts of brick construction on the operation and maintenance of the building of which it is part. Also not considered are the supply-chain impacts of energy production, or supply-chain impacts of equipment.

The lifespan of a brick wall is approximately 100 years (although many brick structures clearly last longer than this). Thus the high embodied energy of brick should be weighed against its durability when comparing to other materials.

Most water is used during extraction, primarily for processing prior to manufacturing. More research is needed to verify these rough figures, to establish whether any water is reused, and to understand the quality of any water released.

Additional environmental impacts not quantified in this study include the following:

Land use impacts. Quarrying clay and construction of a building can disrupt habitat and contribute to soil erosion. However, clay mines are relatively shallow and are often reclaimed after use. Material use / waste. Wasted material accumulates at each stage of the life cycle. However, clay mines produce less waste than other types of mining, and scrap produced during manufacturing is often collected and reincorporated into subsequent batches. During construction, a waste factor of 5% for brick and 25% for mortar is typical. Finally, while landfilling has been assumed here, many opportunities exist for reuse or recycling of brick.

<table>
<thead>
<tr>
<th>METRICS BY LIFE CYCLE STAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECONOMIC INDICATORS</td>
</tr>
<tr>
<td>COST (US dollars per ton brick)</td>
</tr>
<tr>
<td>$527 (70%)</td>
</tr>
<tr>
<td>$106 (14%)</td>
</tr>
<tr>
<td>$45 (6%)</td>
</tr>
<tr>
<td>$55 (9%)</td>
</tr>
<tr>
<td>$12 (2%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ENVIRONMENTAL INDICATORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GREENHOUSE GAS EMISSIONS (lbs CO2-e per ton brick)</td>
</tr>
<tr>
<td>786.0 (95%)</td>
</tr>
<tr>
<td>0.1 (0%)</td>
</tr>
<tr>
<td>37.9 (5%)</td>
</tr>
<tr>
<td>WATER USE (gallons per ton brick)</td>
</tr>
<tr>
<td>2000 (95%)</td>
</tr>
<tr>
<td>0.1 (0%)</td>
</tr>
<tr>
<td>47 (1%)</td>
</tr>
</tbody>
</table>

Note: percentages may not sum to 100% due to independent rounding.
This data is available in table form on page 17. For complete calculations, see Appendix A.
Many of the lifecycle stages have above-average injury & illness rates, compared to the average of 3.7 across all sectors (represented by the dashed line above). The surprising exception is clay mining. The data has been made as specific as possible; however, different lifecycle stages have varying levels of specificity. The following are the categories / sectors from which the data was drawn:

- **Extraction**: Clay and ceramic and refractory minerals mining (NAICS 212325).
- **Manufacturing**: Brick and structural clay tile manufacturing (NAICS 327121).
- **Construction**: Masonry contractors (NAICS 23814).
- **Operations**: N/A
- **End of life**: Solid waste landfill workers (NAICS 562212).
- **Transportation**: General freight trucking, long distance (NAICS 48412).

All but one of the life cycle stages have fatality rates that are substantially higher than the average of 3.3 across all sectors. Indeed, several occupations appear on the U.S. Bureau of Labor Statistics’ list of “Selected Occupations with High Fatal Injury Rates, 2009.” However, is data is far less specific than the injury / illness data. The following are the (more general) categories / sectors from which the data was drawn:

- **Extraction**: Mining.
- **Manufacturing**: Manufacturing sector.
- **Construction**: Construction laborers.
- **Operations**: N/A
- **End of life**: Refuse & recyclable material collectors.
- **Transportation**: Driver/sales workers and truck drivers.

Ideally all three ethical indicators should use the same (and very specific) categories. Such data may be available from the U.S. Bureau of Labor Statistics.

Extraction and construction workers are paid close to or higher than the average annual salary of $42,340 in Ohio. Relative to the injury/illness rates, the pay appears fair (or even generous). However, compared to the fatality rates, the pay is not proportional to the increased risk. Overall, and given the uncertainty of the fatality rate data, the analysis suggests that these jobs are reasonably fair and equitable.

Transportation, manufacturing, and waste management workers, on the other hand, earn less than the average annual salary and yet bear substantially higher rates of both injury/illness and fatality. This suggests that these jobs are exploitative.

Mean and median annual wages do not appear to differ markedly in the sectors for which data was available.
Why compare? Performing an LCA entails making numerous assumptions and utilizing data that is not always perfectly up-to-date, representative, or complete. By comparing the findings of this study to findings from other sources utilizing other methodologies, we can see whether the findings match or whether there are major discrepancies. Future research could compare to product-orientated LCA tools such as BEES or the Athena Impact Estimator.¹

What is EIOLCA? EIOLCA stands for Economic Input Output Life Cycle Assessment. It is a macro-scale LCA tool first proposed by economist Wassily Leontief, and operationalized by researchers at Carnegie Mellon University. It uses industry-wide data to estimate materials and energy resources required for, and the environmental emissions resulting from, the activities of specific economic sectors: "The method uses information about industry transactions—purchases of materials by one industry from other industries, and the information about direct environmental emissions of industries, to estimate the total emissions throughout the supply chain."²

Comparison of Scope The analysis performed here was cradle-to-grave: from extraction of raw materials through the end of the product’s life. EIOLCA’s assessment is cradle-to-gate: from the extraction of raw materials to the gate of the manufacturing facility. Therefore, EIOLCA does not take into account impacts from transportation to the site, construction, or end of life. Within its cradle-to-gate scope, however, EIOLCA is extremely comprehensive, including all transactions through the entire supply chain.³ Whereas the scope of this assessment did not even include all of the components of brick (metals and other additives)—let alone the life-cycle impacts of the machinery required to manufacture brick or the supply chain of power generation (oil and gas extraction, coal mining, pipeline transportation, etc.)—EIOLCA includes all of this and more. A final difference is EIOLCA’s uses industry-wide averages rather than site-specific values. My analysis used a combination of the two, favoring site-specific data where available.

Comparison of Data Two metrics that appear in both assessments—economic activity and GHG emissions—are compared in the table below. There are two primary discrepancies: First, EIOLCA allocates a much smaller percentage of economic activity to extraction (even adjusting for differences in scope): 2.5% vs. 29.8%. This may be the result of mismatched metrics that are not tracking comparable data. Nonetheless, the cost data used in this analysis should be verified. Second, EIOLCA shows a large portion of GHG emissions resulting from power generation and its supply chain, which were not included in this analysis. When the scopes are properly matched (including revising the transportation figure to reflect only industry average cradle-to-gate data), the allocation of GHG emissions across life cycle stages are nearly identical. Therefore, if one accounts for the differences in scope and data, the two analyses appear to agree, particularly regarding the large energy and GHG implications of brick manufacturing.

Finally, EIOLCA reveals that there are toxic releases associated with many of the brick additives—the small amounts of metals added to brick (primarily for coloring). How many of these materials are unnecessary and could be avoided? ("No artificial colors").
ECONOMICS

Summary
Brick is expensive, but a large part of this expense is paying for human labor (craftsmanship) rather than material or energy use. Whether this trade-off is "worth it" financially depends upon the values and goals of the designer and/or client. Brick bearing wall structures are very durable, so the high initial cost may be offset by its long lifespan.

Recommendations for Designers
Because of its high up-front costs and long life, brick may make the most financial sense for government and institutional clients who are invested in the life of the building and may be more willing to pay for long-term durability. Life cycle cost assessment may help to quantify the long-term benefits of durability (although the value of future benefits depends heavily on the discount rate used). Detailing and mortar specifications that reduce the frequency of repointing may reduce the life cycle cost.

Recommendations for Manufacturers
Reducing energy use and improving material efficiency may help to reduce the cost of brick; however, as noted above, the primary cost is incurred during construction rather than manufacturing. Innovations in pre-manufactured brick walls could reduce cost, but should be evaluated for effects on durability and life-cycle cost.

Note: This analysis has focused on monolithic brick bearing walls rather than brick veneer, which typically has a much shorter lifespan (40-60 years, rather than 100+). Further research could focus on comparing the life-cycle cost (LCC) of the two.

ENVIRONMENT

Summary
The primary environmental concern with brick is the energy used in manufacturing. While brick does, indeed, have high embodied energy, this cost must be divided by its lifespan, and compared in equivalent terms to any alternatives.

Recommendations for Designers
Because of brick's high embodied energy, durability is a primary concern. Designers should focus on creating a building that is highly flexible and adaptable to many future uses, as well as emphasizing careful detailing to extend the wall's life.1

In addition, designers should look for manufacturers that (1) use renewable energy and/or actively seek to reduce brick's embodied energy, and (2) extract and manufacture the product locally (to minimize transportation impacts).

Finally, designers should take advantage of brick's thermal mass effects in order to reduce the building's operating energy use.

Recommendations for Manufacturers
Manufacturers must focus on reducing the energy impact of brick in ways that do not compromise its durability. This could be done by using renewable energy, including carbon-neutral sources of natural gas (e.g., biogas). Longer pre-firing times may reduce the energy required to fire bricks. Lighter-weight bricks may reduce the energy used in transportation (although this is a not a primary concern, as transportation energy was not found to be significant).

In addition, manufacturers should focus on brick's end-of-life trajectory. Following William McDonough and Michael Braungart's "cradle-to-cradle" philosophy,2 manufacturers should look carefully at the material chemistry of bricks in order to create a product that can be safely returned to the biosphere at the end of its life. EOLCA shows that there are currently toxic outputs resulting from metal additives—manufacturers should work to eliminate such toxins.

Finally, manufacturers could find ways to take back bricks and/or incorporate additional recycled material (mindful of any effects on durability).

ETHICS

Summary
Based upon injury, fatality, and wage data, brick bearing walls appear to be at least slightly exploitative throughout their life cycle, although likely less so than other building materials. The fatality rate is unacceptably high for several of its life cycle stages.

Recommendations for Designers
First, designers should work with clients to prioritize ethical impacts of buildings (in addition to environmental and economic impacts). Second, designers should seek out manufacturers who prioritize worker safety, pay fair wages, and provide good health benefits. Similarly, designers should look for contractors who emphasize safety, fair pay, and good benefits. These criteria could go a long way toward improving the ethical impacts of brick walls specifically, and construction more generally.

Recommendations for Manufacturers
Manufacturers must focus on improving worker safety—specifically on reducing injuries during brick manufacturing and fatalities during clay extraction. Manufacturers should also favor forms of transportation that reduce illness, injury, and fatality.

1. The Building Science Corporation (www.buildingscience.com) and the Brick Industry Association (www.gobrick.com) both provide excellent resources on detailing for durability.
2. See McDonough and Braungart, Cradle to Cradle.


## Life Cycle Assessment: Brick Bearing Wall, Longworth Hall, Cincinnati, Ohio

Carl S. Sterner

### BRICK LCA APPENDIX A: DATA & SOURCES

#### Overall LCA Data

<table>
<thead>
<tr>
<th>Metric</th>
<th>Extraction / Harvest</th>
<th>Manufacturing</th>
<th>Shipping / Transport</th>
<th>Construction</th>
<th>Operations</th>
<th>End of Life (Landfill)</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Units</td>
<td>Quantity</td>
<td>Quantity</td>
<td>Quantity</td>
<td>Quantity</td>
<td>Quantity</td>
<td>Quantity</td>
</tr>
<tr>
<td></td>
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<td>Source</td>
<td>Source</td>
<td>Source</td>
<td>Source</td>
<td>Source</td>
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</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ECONOMIC</strong></td>
<td>$ / sq. ft. wall</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>$2.90 [1]</td>
<td>NO DATA</td>
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<tr>
<td></td>
<td>$ / ton</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>$123.82 calc.</td>
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<tr>
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<td>$ / sq. ft. wall</td>
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<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>$6.08 [1]</td>
<td>NO DATA</td>
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<tr>
<td></td>
<td>$ / ton</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>$259.60 calc.</td>
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<td></td>
<td>$ / sq. ft. wall</td>
<td>$1.05 calc.</td>
<td>$2.47 calc.</td>
<td>$1.53 calc.</td>
<td>$12.34 [1]</td>
<td>$0.28 calc.</td>
<td>$11.84</td>
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<tr>
<td></td>
<td>$ / ton</td>
<td>$44.81 [14]</td>
<td>$105.62 calc.</td>
<td>$65.16 [24,25]</td>
<td>$526.88 calc.</td>
<td>$17.67</td>
<td>$754.31</td>
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</table>

### ENVIRONMENTAL

<table>
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<tr>
<th>Emissions to air</th>
<th>Total GHG emissions</th>
<th>lbs CO2e / ton</th>
<th>786.07 calc.</th>
<th>16122.19 [1]</th>
<th>NO DATA</th>
<th>37.88 [16]</th>
<th>NO DATA</th>
<th>NO DATA</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>GHN emissions from electricity</td>
<td>lbs CO2e / ton</td>
<td>633.53 [22]</td>
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<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
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<tr>
<td></td>
<td>GHN emissions from nat. gas</td>
<td>lbs CO2e / ton</td>
<td>152.54 [23]</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
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<tr>
<td></td>
<td>Energy use</td>
<td>MMBTU / ton</td>
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<td>1.6667 [20]</td>
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<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
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<tr>
<td></td>
<td>Electricity</td>
<td>MMBTU / ton</td>
<td>NO DATA</td>
<td>0.1207 [20]</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
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<tr>
<td></td>
<td>Natural gas</td>
<td>MMBTU / ton</td>
<td>NO DATA</td>
<td>1.3040 [20]</td>
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<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
</tr>
<tr>
<td></td>
<td>Water use</td>
<td>gal / ton</td>
<td>2000 [19]</td>
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<td>NO DATA</td>
<td>100 est.</td>
<td>NO DATA</td>
<td>NO DATA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

### ETICAL

<table>
<thead>
<tr>
<th>Injury / Illness rate</th>
<th>cases per 100 employees</th>
<th>3.4 [16]</th>
<th>7.0 [16]</th>
<th>5.5 [16]</th>
<th>4.6 [16]</th>
<th>5.5 [16]</th>
<th>5.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>relative to all occupations</td>
<td>%</td>
<td>91.9% [16]</td>
<td>180.2% [16]</td>
<td>148.6% [16]</td>
<td>124.3% [16]</td>
<td>140.5%</td>
<td>140.5%</td>
</tr>
<tr>
<td>relative to all occupations</td>
<td>%</td>
<td>384.8% [10]</td>
<td>56.7% [31]</td>
<td>85.3% [1]</td>
<td>95.6% [2]</td>
<td>440.8%</td>
<td>440.8%</td>
</tr>
<tr>
<td>% of local avg. wage</td>
<td>%</td>
<td>99% calc.</td>
<td>75% calc.</td>
<td>97.2% [29]</td>
<td>118% [2]</td>
<td>88.1% [2]</td>
<td>95.5%</td>
</tr>
<tr>
<td>Median %</td>
<td>121% calc.</td>
<td>96% calc.</td>
<td>118.7% [29]</td>
<td>155% [2]</td>
<td>NO DATA</td>
<td>122.6%</td>
<td></td>
</tr>
</tbody>
</table>

### Sources

4. [http://www.longworthhall.com/about.html](http://www.longworthhall.com/about.html)
7. [http://www.reado.com/Particle_Briefings/spec_gra2.html](http://www.reado.com/Particle_Briefings/spec_gra2.html)
Source of Charts and Information:

- **ECONOMIC:**
  - Material cost
  - Power generation (s.f. wall)
  - Transportation
  - End of Life
  - Extraction

- **ENVIRONMENTAL:**
  - GHG emissions
  - Water use

- **ETHICAL:**
  - Injury / Illness rate
  - Fatality rate
  - Mean annual wage
  - Median annual wage

- **Comparison to EIOLCA:**
  - Total cost
  - Cost without

Summary Table (Source for Charts):

<table>
<thead>
<tr>
<th>Activity</th>
<th>US $ per ton</th>
<th>% of total</th>
<th>lbs CO2-e per ton</th>
<th>% of total</th>
<th>gallons per ton</th>
<th>% of total</th>
<th>Cases per 100 emp.</th>
<th>Per 100,000 emp.</th>
<th>Cincinnati; 2010 US $</th>
<th>Cincinnati; 2010 US $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction</td>
<td>$45</td>
<td>6%</td>
<td>0.10</td>
<td>0%</td>
<td>2000</td>
<td>95%</td>
<td>3.4</td>
<td>12.7</td>
<td>$41,922</td>
<td>$39,977</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>$106</td>
<td>14%</td>
<td>786.07</td>
<td>95%</td>
<td>0</td>
<td>0%</td>
<td>7.0</td>
<td>2.2</td>
<td>$31,677</td>
<td>$31,483</td>
</tr>
<tr>
<td>Construction</td>
<td>$527</td>
<td>70%</td>
<td>0.00</td>
<td>0%</td>
<td>100</td>
<td>5%</td>
<td>4.6</td>
<td>18.3</td>
<td>$50,110</td>
<td>$51,070</td>
</tr>
<tr>
<td>Operation</td>
<td>$12</td>
<td>2%</td>
<td>0.04</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>5.5</td>
<td>25.2</td>
<td>$37,290</td>
<td>$37,770</td>
</tr>
<tr>
<td>End of Life</td>
<td>$65</td>
<td>9%</td>
<td>37.88</td>
<td>5%</td>
<td>0</td>
<td>0%</td>
<td>5.5</td>
<td>18.3</td>
<td>$39,180</td>
<td>$37,770</td>
</tr>
<tr>
<td>TOTAL / AVG.</td>
<td>$754</td>
<td>100%</td>
<td>824.10</td>
<td>100%</td>
<td>2100</td>
<td>100%</td>
<td>3.7</td>
<td>3.3</td>
<td>$42,340</td>
<td>$32,950</td>
</tr>
</tbody>
</table>

Conversions:

- 1 metric ton = 1.1023113 tons
- 1 s.f. wall = 0.109 c.f. mortar
- 1 s.f. wall = 0.01606328 c.f. brick
Extraction of Common Clay

Economic data from USGS (see reference [f] below), based on all domestic clay manufacturing (including non-brick uses, which account for roughly 54% of clay produced). Emission data uses limestone extraction as an approximation (clay data was unavailable; data from the U.S. LCI database. Water use is a rough estimate for clay mining, from a report to the Dept. of Energy by CH2M Hill (see reference [h] below). Ethical data from the U.S. Bureau of Labor Statistics, as follows: wage data based upon "Nonmetallic Mineral Mining and Quarrying," NAICS code 212300; fatality data based upon general "mining" sector data (see reference [e] below); injury/illness data based upon "Clay and ceramic and refractory minerals mining" (see reference [a] below).

### Overall Industry Data

<table>
<thead>
<tr>
<th>Metric</th>
<th>Units</th>
<th>Quantity</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material cost</td>
<td>$ / ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor cost</td>
<td>$ / ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost</td>
<td>$ / ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total revenue</td>
<td>$ / ton</td>
<td>$44.81</td>
<td>[f]</td>
</tr>
<tr>
<td>Emissions to air</td>
<td>Tons / ton</td>
<td>0.1022 [g]</td>
<td></td>
</tr>
<tr>
<td>Total GHG emissions</td>
<td>lbs CO2e / ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical</td>
<td>MMBTU / ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>MMBTU / ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water use</td>
<td>gal / ton</td>
<td>2000 [h]</td>
<td></td>
</tr>
</tbody>
</table>

### Ethical Data

<table>
<thead>
<tr>
<th>Injury / illness rate</th>
<th>cases per 100 employees</th>
<th>3.4 [a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>relative to all occupations</td>
<td>%</td>
<td>91.9%</td>
</tr>
<tr>
<td>Fatality rate</td>
<td>per 100,000 / yr</td>
<td>12.7 [e]</td>
</tr>
<tr>
<td>relative to all occupations</td>
<td>%</td>
<td>384.8%</td>
</tr>
<tr>
<td>Annual wage (Cincinnati)</td>
<td>$ / yr</td>
<td>$41,922 calc.</td>
</tr>
<tr>
<td>Mean</td>
<td>99% calc.</td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>121% calc.</td>
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</tbody>
</table>

### Sources

[b] NOT USED
[d] NOT USED
[f] NOT USED

### TOTAL COST - EXTRACTION

<table>
<thead>
<tr>
<th>Units</th>
<th>2006</th>
<th>2008</th>
<th>Source</th>
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<tbody>
<tr>
<td>Metric tons</td>
<td>$6,700,000</td>
<td>$3,200,000</td>
<td>[f]</td>
</tr>
<tr>
<td>Value</td>
<td>$1,750,000,000</td>
<td>$1,640,000,000</td>
<td>[f]</td>
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<tr>
<td>Unit Value</td>
<td>per metric ton</td>
<td>$47.68</td>
<td>$49.40</td>
</tr>
<tr>
<td>Unit Value</td>
<td>per short ton</td>
<td>$43.26</td>
<td>$44.81</td>
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</table>

### Conversions

<table>
<thead>
<tr>
<th>Conversion</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 metric ton</td>
<td>=</td>
</tr>
<tr>
<td>1 kg</td>
<td>= 1.1023113 short tons</td>
</tr>
<tr>
<td>1 kg</td>
<td>= 0.0000511 kg CO2-e</td>
</tr>
<tr>
<td>1 metric ton</td>
<td>= 0.0511 kg CO2-e</td>
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<tr>
<td>1 short ton</td>
<td>= 0.064357141 kg CO2-e</td>
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<tr>
<td>1 short ton</td>
<td>= 0.1022 lbs CO2-e</td>
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### GHG EMISSIONS / CONVERSIONS

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>kg CO2-e</td>
<td>=</td>
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<tr>
<td>kg CO2-e</td>
<td>= 0.064357141 kg CO2-e</td>
</tr>
<tr>
<td>kg CO2-e</td>
<td>= 0.0511 kg CO2-e</td>
</tr>
<tr>
<td>lbs CO2-e</td>
<td>= 0.1022 lbs CO2-e</td>
</tr>
<tr>
<td>lbs CO2-e</td>
<td>=</td>
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APPENDIX A: DATA & SOURCES
### AVERAGE WAGES - EXTRACTION

<table>
<thead>
<tr>
<th>SOC Code Number</th>
<th>Occupation</th>
<th>Mean Annual Wage (national)</th>
<th>Weighted Mean Annual Wage (national)</th>
<th>Mean Annual Wage (Cincinnati)</th>
<th>Weighted Mean Annual Wage (Cincinnati)</th>
<th>% of Total Industry</th>
<th>Weighted Median Annual Wage (Cincinnati)</th>
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<tbody>
<tr>
<td>11-1011</td>
<td>Chief Executives</td>
<td>$176,130</td>
<td>$172,730</td>
<td>$172,730</td>
<td>$172,730</td>
<td>0.21%</td>
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<tr>
<td>11-1021</td>
<td>General and Operations Managers</td>
<td>$99,940</td>
<td>$111,400</td>
<td>$212,774,000</td>
<td>$101,980</td>
<td>1.95%</td>
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</tr>
<tr>
<td>11-2022</td>
<td>Sales Managers</td>
<td>$99,650</td>
<td>$114,620</td>
<td>$16,046,800</td>
<td>$101,390</td>
<td>0.14%</td>
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<tr>
<td>11-3031</td>
<td>Financial Managers</td>
<td>$93,620</td>
<td>$109,240</td>
<td>$19,663,200</td>
<td>$99,890</td>
<td>0.18%</td>
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<tr>
<td>11-3051</td>
<td>Industrial Production Managers</td>
<td>$86,150</td>
<td>$96,290</td>
<td>$52,959,500</td>
<td>$88,020</td>
<td>0.56%</td>
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<tr>
<td>11-3061</td>
<td>Purchasing Managers</td>
<td>$80,390</td>
<td>$91,560</td>
<td>$3,662,400</td>
<td>$87,490</td>
<td>0.04%</td>
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</tr>
<tr>
<td>11-3071</td>
<td>Transportation, Storage, and T</td>
<td>$96,810</td>
<td>$81,940</td>
<td>$4,097,000</td>
<td>$77,560</td>
<td>0.05%</td>
<td></td>
</tr>
<tr>
<td>11-3091</td>
<td>Construction Managers</td>
<td>$93,910</td>
<td>$98,260</td>
<td>$19,452,000</td>
<td>$85,600</td>
<td>0.20%</td>
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<tr>
<td>11-9041</td>
<td>Engineering Managers</td>
<td>$110,090</td>
<td>$122,700</td>
<td>$12,270,000</td>
<td>$114,330</td>
<td>0.10%</td>
<td></td>
</tr>
<tr>
<td>11-9199</td>
<td>Managers, All Other</td>
<td>$78,890</td>
<td>$108,120</td>
<td>$14,055,600</td>
<td>$102,910</td>
<td>0.13%</td>
<td></td>
</tr>
<tr>
<td>13-1023</td>
<td>Purchasing Agents, Except Wh</td>
<td>$51,300</td>
<td>$56,340</td>
<td>$14,085,000</td>
<td>$53,680</td>
<td>0.26%</td>
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<tr>
<td>13-1041</td>
<td>Compliance Officers, Except A</td>
<td>$55,430</td>
<td>$56,970</td>
<td>$3,847,900</td>
<td>$50,410</td>
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<tr>
<td>13-1051</td>
<td>Cost Estimators</td>
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<td>$55,780</td>
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<tr>
<td>13-1073</td>
<td>Training and Development Sp</td>
<td>$53,060</td>
<td>$55,060</td>
<td>$2,122,400</td>
<td>$50,050</td>
<td>0.04%</td>
<td></td>
</tr>
<tr>
<td>13-1079</td>
<td>Human Resources, Training, a</td>
<td>$53,040</td>
<td>$52,440</td>
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<td>$49,580</td>
<td>0.06%</td>
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</tr>
<tr>
<td>13-1199</td>
<td>Business Operations Specialist</td>
<td>$54,280</td>
<td>$61,170</td>
<td>$4,893,600</td>
<td>$57,050</td>
<td>0.08%</td>
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</tr>
<tr>
<td>13-2011</td>
<td>Accountants and Auditors</td>
<td>$68,290</td>
<td>$63,950</td>
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<td>$57,530</td>
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<tr>
<td>15-1041</td>
<td>Computer Support Specialists</td>
<td>$48,140</td>
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<td>$42,240</td>
<td>0.03%</td>
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</tr>
<tr>
<td>15-1071</td>
<td>Network and Computer Syst</td>
<td>$62,930</td>
<td>$64,650</td>
<td>$2,586,000</td>
<td>$63,940</td>
<td>0.04%</td>
<td></td>
</tr>
<tr>
<td>17-1022</td>
<td>Surveyors</td>
<td>$52,200</td>
<td>$55,770</td>
<td>$2,230,800</td>
<td>$53,640</td>
<td>0.04%</td>
<td></td>
</tr>
<tr>
<td>17-2041</td>
<td>Chemical Engineers</td>
<td>$92,910</td>
<td>$92,910</td>
<td>$2,694,300</td>
<td>$81,890</td>
<td>0.33%</td>
<td></td>
</tr>
<tr>
<td>17-2051</td>
<td>Civil Engineers</td>
<td>$66,580</td>
<td>$76,940</td>
<td>$3,077,600</td>
<td>$74,130</td>
<td>0.04%</td>
<td></td>
</tr>
<tr>
<td>17-2081</td>
<td>Environmental Engineers</td>
<td>$74,700</td>
<td>$89,480</td>
<td>$3,368,800</td>
<td>$84,560</td>
<td>0.06%</td>
<td></td>
</tr>
<tr>
<td>17-2111</td>
<td>Health and Safety Engineers, I</td>
<td>$79,600</td>
<td>$74,880</td>
<td>$2,983,200</td>
<td>$70,820</td>
<td>0.04%</td>
<td></td>
</tr>
<tr>
<td>17-2112</td>
<td>Industrial Engineers</td>
<td>$71,350</td>
<td>$76,380</td>
<td>$16,039,800</td>
<td>$73,660</td>
<td>0.21%</td>
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</tr>
<tr>
<td>17-2141</td>
<td>Mechanical Engineers</td>
<td>$72,770</td>
<td>$76,120</td>
<td>$3,044,800</td>
<td>$69,850</td>
<td>0.04%</td>
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<tr>
<td>17-2151</td>
<td>Mining and Geological Engineer</td>
<td>$72,040</td>
<td>$78,510</td>
<td>$24,338,100</td>
<td>$76,070</td>
<td>0.32%</td>
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<tr>
<td>17-2199</td>
<td>Engineers, All Other</td>
<td>$57,240</td>
<td>$78,510</td>
<td>$3,140,400</td>
<td>$76,070</td>
<td>0.04%</td>
<td></td>
</tr>
<tr>
<td>17-3026</td>
<td>Industrial Engineering Technic</td>
<td>$48,700</td>
<td>$48,230</td>
<td>$2,411,500</td>
<td>$47,900</td>
<td>0.05%</td>
<td></td>
</tr>
<tr>
<td>19-4031</td>
<td>Chemical Technicians</td>
<td>$45,460</td>
<td>$42,330</td>
<td>$24,128,100</td>
<td>$41,000</td>
<td>0.58%</td>
<td></td>
</tr>
<tr>
<td>19-4099</td>
<td>Life, Physical, and Social Scien</td>
<td>$42,270</td>
<td>$42,990</td>
<td>$1,719,600</td>
<td>$39,430</td>
<td>0.04%</td>
<td></td>
</tr>
<tr>
<td>29-9011</td>
<td>Occupational Health and Safet</td>
<td>$60,620</td>
<td>$68,190</td>
<td>$8,864,700</td>
<td>$66,410</td>
<td>0.13%</td>
<td></td>
</tr>
<tr>
<td>33-9032</td>
<td>Security Guards</td>
<td>$23,170</td>
<td>$26,520</td>
<td>$1,856,400</td>
<td>$23,120</td>
<td>0.07%</td>
<td></td>
</tr>
<tr>
<td>37-3011</td>
<td>Janitors and Cleaners, Except</td>
<td>$26,310</td>
<td>$24,140</td>
<td>$4,586,600</td>
<td>$22,260</td>
<td>0.19%</td>
<td></td>
</tr>
<tr>
<td>37-3011</td>
<td>Landscaping and Groundskeep</td>
<td>$24,500</td>
<td>$24,170</td>
<td>$2,658,700</td>
<td>$21,980</td>
<td>0.11%</td>
<td></td>
</tr>
<tr>
<td>41-2031</td>
<td>Retail Salespersons</td>
<td>$26,070</td>
<td>$24,700</td>
<td>$0</td>
<td>$19,640</td>
<td>0.58%</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>----------</td>
<td>----------</td>
<td>------------</td>
<td>----------------</td>
<td>--------</td>
<td>----------------</td>
<td>--------</td>
</tr>
<tr>
<td>Sales Representatives, Services</td>
<td>41-3099</td>
<td>100</td>
<td>0.10%</td>
<td>$63,880</td>
<td>$6,388,000</td>
<td>$54,080</td>
<td>$5,408,000</td>
</tr>
<tr>
<td>Total</td>
<td>41-4012</td>
<td>1,150</td>
<td>1.17%</td>
<td>$57,440</td>
<td>$6,744,000</td>
<td>$67,140</td>
<td>$7,711,400</td>
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**OFFICE AND ADMINISTRATIVE SUPPORT OCCUPATIONS**

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<tr>
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<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>First-Line Supervisors/Managers</td>
<td>43-1011</td>
<td>610</td>
<td>0.62%</td>
<td>$48,290</td>
<td>$6,429,000</td>
<td>$48,990</td>
<td>$6,499,000</td>
<td>$46,050</td>
<td>$6,050,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>43-1071</td>
<td>2,980</td>
<td>2.04%</td>
<td>$58,900</td>
<td>$7,580,000</td>
<td>$57,920</td>
<td>$7,262,000</td>
<td>$56,560</td>
<td>$6,560,000</td>
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</table>

**CONSTRUCTION AND EXTRATION OCCUPATIONS**

<table>
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<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>First-Line Supervisors/Managers</td>
<td>47-1011</td>
<td>2,980</td>
<td>2.04%</td>
<td>$58,900</td>
<td>$7,580,000</td>
<td>$57,920</td>
<td>$7,262,000</td>
<td>$56,560</td>
<td>$6,560,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>47-1051</td>
<td>2,490</td>
<td>1.80%</td>
<td>$55,227,000</td>
<td>$7,032,000</td>
<td>$54,500</td>
<td>$6,700,000</td>
<td>$53,000</td>
<td>$6,000,000</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**INSTALLATION, MAINTENANCE, AND REPAIR OCCUPATIONS**

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>First-Line Supervisors/Managers</td>
<td>49-1011</td>
<td>2,980</td>
<td>2.04%</td>
<td>$58,900</td>
<td>$7,580,000</td>
<td>$57,920</td>
<td>$7,262,000</td>
<td>$56,560</td>
<td>$6,560,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>49-1051</td>
<td>2,490</td>
<td>1.80%</td>
<td>$55,227,000</td>
<td>$7,032,000</td>
<td>$54,500</td>
<td>$6,700,000</td>
<td>$53,000</td>
<td>$6,000,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PRODUCT OPERATIONS**

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>First-Line Supervisors/Managers</td>
<td>51-1011</td>
<td>2,980</td>
<td>2.04%</td>
<td>$58,900</td>
<td>$7,580,000</td>
<td>$57,920</td>
<td>$7,262,000</td>
<td>$56,560</td>
<td>$6,560,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>51-1051</td>
<td>2,490</td>
<td>1.80%</td>
<td>$55,227,000</td>
<td>$7,032,000</td>
<td>$54,500</td>
<td>$6,700,000</td>
<td>$53,000</td>
<td>$6,000,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### BRICK LCA APPENDIX A: DATA & SOURCES

#### Extraction Data (continued)

| 51-9195 | Molders, Shapers, and Casters | 980 | 1.00% | $35,670 | $27,040 | $27,010 | $25,509,400 | $24,710 | $24,215,800 |
| 51-9198 | Helpers—Production Workers | 460 | 0.47% | $41,480 | $19,080,800 | $29,280 | $13,468,800 | $26,450 | $12,167,000 |

#### TRANSPORTATION AND MATERIAL MOVING OPERATIONS

| 53-1021 | First-Line Supervisors/Managers of Helpers, Laborers, and Material Movers, Hand | 410 | 0.42% | $48,310 | $19,807,100 | $47,200 | $19,352,000 | $44,890 | $18,404,900 |
| 53-1031 | First-Line Supervisors/Managers of Transportation and Material-Moving Machine and Vehicle Operators | 1,200 | 1.23% | $54,820 | $65,784,000 | $53,570 | $64,284,000 | $51,230 | $61,476,000 |
| 53-5021 | Dredge Operators | 1,030 | 1.05% | $35,040 | $36,091,200 | $31,970 | $30,381,000 | $33,690 | $32,005,500 |
| 53-5022 | Excavating and Loading Machine Operators, Hand | 7,390 | 7.55% | $34,410 | $254,289,900 | $40,760 | $301,216,400 | $37,800 | $279,342,000 |
| 53-5023 | Loading Machine Operators, U | 700 | 0.71% | $37,330 | $26,131,000 | $40,760 | $28,532,000 | $37,800 | $26,460,000 |
| 53-5024 | Hoist and Winch Operators | 30 | 0.03% | $44,060 | $1,321,800 | $44,060 | $1,321,800 | $44,060 | $1,321,800 |
| 53-5025 | Industrial Truck and Tractor Operators | 2,150 | 2.20% | $32,890 | $70,713,500 | $30,560 | $65,704,000 | $30,230 | $64,994,500 |
| 53-5026 | Laborers and Freight, Stock, and Material Movers, Hand | 3,660 | 3.74% | $31,510 | $119,332,400 | $23,290 | $89,195,400 | $23,400 | $85,644,000 |
| 53-5027 | Machine Feeders and Offbearers | 310 | 0.32% | $27,610 | $8,559,100 | $29,480 | $9,138,800 | $26,130 | $8,100,300 |

### Total:

- **96,350** employees, **98.28%** of total employment.

**Payroll Data:**

- **$3,921,081,600** in total payroll.
- **$40,696** for average weekly payroll.
- **$3,851,619,900** for total payroll.

**Average Weekly Payroll:**

- **$41,922.24** for average weekly payroll.
- **$39,977.37** for average weekly payroll.

**Additional Notes:**

- The data represents employment and payroll statistics for various occupations within the brick industry, including molders, shapers, and casters, as well as helpers—production workers and transportation and material moving operations.
- The percentages provided indicate the distribution of employment within these categories, with a focus on the number of employees and the total payroll.
## Brick Production: Top Clay-Mining States

### Common Clay and Shale Used in Building Brick Production in the United States, by States

<table>
<thead>
<tr>
<th>State</th>
<th>Quantity (thousand metric tons) 2007</th>
<th>%</th>
<th>Quantity (thousand metric tons) 2008</th>
<th>%</th>
<th>Quantity (thousand metric tons) 2009</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>1320</td>
<td>11.22%</td>
<td>792</td>
<td>8.86%</td>
<td>718</td>
<td>10.04%</td>
</tr>
<tr>
<td>Arkansas</td>
<td>380</td>
<td>3.23%</td>
<td>257</td>
<td>2.91%</td>
<td>220</td>
<td>3.07%</td>
</tr>
<tr>
<td>California</td>
<td>211</td>
<td>1.79%</td>
<td>164</td>
<td>1.86%</td>
<td>131</td>
<td>1.83%</td>
</tr>
<tr>
<td>Colorado</td>
<td>154</td>
<td>1.31%</td>
<td>108</td>
<td>1.22%</td>
<td>91</td>
<td>1.37%</td>
</tr>
<tr>
<td>Georgia</td>
<td>1260</td>
<td>10.71%</td>
<td>884</td>
<td>10.02%</td>
<td>741</td>
<td>10.37%</td>
</tr>
<tr>
<td>Kentucky</td>
<td>409</td>
<td>3.48%</td>
<td>275</td>
<td>3.12%</td>
<td>236</td>
<td>3.30%</td>
</tr>
<tr>
<td>Mississippi</td>
<td>508</td>
<td>4.32%</td>
<td>423</td>
<td>4.91%</td>
<td>330</td>
<td>4.61%</td>
</tr>
<tr>
<td>North Carolina</td>
<td>1650</td>
<td>14.03%</td>
<td>1250</td>
<td>14.17%</td>
<td>1008</td>
<td>14.10%</td>
</tr>
<tr>
<td>Ohio</td>
<td>495</td>
<td>4.21%</td>
<td>379</td>
<td>4.30%</td>
<td>304</td>
<td>4.25%</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>601</td>
<td>5.11%</td>
<td>541</td>
<td>6.13%</td>
<td>402</td>
<td>5.62%</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>603</td>
<td>5.13%</td>
<td>555</td>
<td>6.29%</td>
<td>408</td>
<td>5.71%</td>
</tr>
<tr>
<td>South Carolina</td>
<td>610</td>
<td>5.26%</td>
<td>453</td>
<td>5.13%</td>
<td>372</td>
<td>5.20%</td>
</tr>
<tr>
<td>Tennessee</td>
<td>199</td>
<td>1.69%</td>
<td>155</td>
<td>1.76%</td>
<td>123</td>
<td>1.72%</td>
</tr>
<tr>
<td>Texas</td>
<td>814</td>
<td>6.92%</td>
<td>604</td>
<td>6.85%</td>
<td>492</td>
<td>6.88%</td>
</tr>
<tr>
<td>Virginia</td>
<td>561</td>
<td>4.77%</td>
<td>502</td>
<td>5.69%</td>
<td>374</td>
<td>5.23%</td>
</tr>
<tr>
<td>Other</td>
<td>1980</td>
<td>16.83%</td>
<td>1480</td>
<td>16.78%</td>
<td>1201</td>
<td>16.80%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>11764</td>
<td>57.11%</td>
<td>8822</td>
<td>57.29%</td>
<td>7150</td>
<td>57.20%</td>
</tr>
</tbody>
</table>

| % for Brick    | 57.11%                               | 57.29% | 57.20%                               |
| Total Common Clay | 20,600                           | 15,400 | 12,500                               |

| Top 4 Total:   | 3520                                 | 39.90% |

### Common Clay used in Brick, Production by State

![Graph showing common clay used in brick production by state for 2007, 2008, and 2009.]

- Other
- Virginia
- Texas
- Tennessee
- South Carolina
- Pennsylvania
- Oklahoma
- Ohio
- North Carolina
- Mississippi
- Kentucky
- Georgia
- Colorado
- California
- Arkansas
- Alabama
# Manufacturing Data

## Economic Data and Sources

### Economic Data

<table>
<thead>
<tr>
<th>Metric</th>
<th>Units</th>
<th>Assessment #UA0022</th>
<th>Assessment #NC0352</th>
<th>Assessment #CO0578</th>
<th>Average / Overall Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material cost</td>
<td>$ / ton</td>
<td>$17,000,000</td>
<td>$8,000,000</td>
<td>$22,000,000</td>
<td>$17,000,000</td>
</tr>
<tr>
<td>Labor cost</td>
<td>$ / ton</td>
<td>$8,000,000</td>
<td>$4,000,000</td>
<td>$12,000,000</td>
<td>$8,000,000</td>
</tr>
<tr>
<td>Total sales</td>
<td>dollars</td>
<td>$25,000,000</td>
<td>$12,000,000</td>
<td>$34,000,000</td>
<td>$25,000,000</td>
</tr>
<tr>
<td>Total output</td>
<td>bricks</td>
<td>118,000,000</td>
<td>160,000,000</td>
<td>42,000,000</td>
<td>71,000,000</td>
</tr>
<tr>
<td>Revenue per unit</td>
<td>$ / brick</td>
<td>$0.14</td>
<td>$0.05</td>
<td>$0.52</td>
<td>$0.24 calculated</td>
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<td>Revenue per ton</td>
<td>$ / ton</td>
<td>$63.59</td>
<td>$22.07</td>
<td>$231.20</td>
<td>$105.62 calculated</td>
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</table>

### Environmental Data

<table>
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<tr>
<th>Metric</th>
<th>Units</th>
<th>Assessment #UA0022</th>
<th>Assessment #NC0352</th>
<th>Assessment #CO0578</th>
<th>Average / Overall Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions to air</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHG emissions</td>
<td>lbs CO2e / ton</td>
<td>2,500,000</td>
<td>1,200,000</td>
<td>500,000</td>
<td>1,990,000 calculated</td>
</tr>
<tr>
<td>GHG emissions from electricity</td>
<td>lbs CO2e / ton</td>
<td>1,200,000</td>
<td>600,000</td>
<td>200,000</td>
<td>1,000,000 calculated</td>
</tr>
<tr>
<td>Natural Gas emissions</td>
<td>lbs CO2e / ton</td>
<td>1,200,000</td>
<td>600,000</td>
<td>200,000</td>
<td>1,000,000 calculated</td>
</tr>
<tr>
<td>Energy use</td>
<td>MMBtu</td>
<td>164,972</td>
<td>375,030</td>
<td>162,802</td>
<td>78,168 calculated</td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh</td>
<td>9,164,168</td>
<td>11,078,300</td>
<td>3,931,200</td>
<td>22,000 calculated</td>
</tr>
<tr>
<td>Electricity % of total</td>
<td>%</td>
<td>20.65%</td>
<td>19.75%</td>
<td>24.74%</td>
<td>22% calculated</td>
</tr>
<tr>
<td>Natural Gas % of total</td>
<td>%</td>
<td>79.35%</td>
<td>80.25%</td>
<td>75.26%</td>
<td>78% calculated</td>
</tr>
<tr>
<td>Energy use per ton</td>
<td>MMBtu / ton</td>
<td>2,500,000</td>
<td>375,030</td>
<td>162,802</td>
<td>78,168 calculated</td>
</tr>
<tr>
<td>Electricity</td>
<td>MMBtu / ton</td>
<td>120,000</td>
<td>25,000</td>
<td>10,000</td>
<td>60,000 calculated</td>
</tr>
<tr>
<td>Energy use per unit</td>
<td>Btu / brick</td>
<td>2,500,000</td>
<td>375,030</td>
<td>162,802</td>
<td>78,168 calculated</td>
</tr>
<tr>
<td>Electricity</td>
<td>Btu / brick</td>
<td>120,000</td>
<td>25,000</td>
<td>10,000</td>
<td>60,000 calculated</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>Btu / brick</td>
<td>2,500,000</td>
<td>375,030</td>
<td>162,802</td>
<td>78,168 calculated</td>
</tr>
<tr>
<td>Water use</td>
<td>gal / ton</td>
<td>50,000</td>
<td>12,000</td>
<td>3,000</td>
<td>31,000 calculated</td>
</tr>
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</table>

### Ethical Data

<table>
<thead>
<tr>
<th>Metric</th>
<th>Source</th>
<th>Assessment #UA0022</th>
<th>Assessment #NC0352</th>
<th>Assessment #CO0578</th>
<th>Average / Overall Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury / illness rate</td>
<td>cases per 100 employees</td>
<td>7.0 [a]</td>
<td>189.2% [a]</td>
<td>3.2 [e]</td>
<td>75% calculated</td>
</tr>
<tr>
<td>relative to all occupations</td>
<td>%</td>
<td>7.0 [a]</td>
<td>3.2 [e]</td>
<td>75% calculated</td>
<td></td>
</tr>
<tr>
<td>Fatality rate</td>
<td>per 100,000 / yr</td>
<td>2.2 [e]</td>
<td>2.2 [e]</td>
<td>2.2 [e]</td>
<td>2.2 [e]</td>
</tr>
<tr>
<td>relative to all occupations</td>
<td>%</td>
<td>3.2 [e]</td>
<td>3.2 [e]</td>
<td>3.2 [e]</td>
<td>3.2 [e]</td>
</tr>
<tr>
<td>Annual wage (Cincinnati)</td>
<td>$ / yr</td>
<td>$33,483</td>
<td>$189,200</td>
<td>$33,483</td>
<td>$189,200 calculated</td>
</tr>
<tr>
<td>Mean</td>
<td>$ / yr</td>
<td>33,483</td>
<td>189,200</td>
<td>33,483</td>
<td>189,200 calculated</td>
</tr>
<tr>
<td>Median</td>
<td>$ / yr</td>
<td>$33,483</td>
<td>$189,200</td>
<td>$33,483</td>
<td>$189,200 calculated</td>
</tr>
</tbody>
</table>

---

**Sources:**


**Notes:**

Sources


EMISSION FACTORS

<table>
<thead>
<tr>
<th>Emission Factor</th>
<th>Units</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MMBTU natural gas</td>
<td></td>
<td>[i]</td>
</tr>
<tr>
<td>1 MWh electricity in Ohio</td>
<td></td>
<td>[j]</td>
</tr>
<tr>
<td>1 MWh</td>
<td></td>
<td>[k]</td>
</tr>
<tr>
<td>1 MMBTU</td>
<td></td>
<td>given</td>
</tr>
<tr>
<td>1 MMBTU electricity in Ohio</td>
<td></td>
<td>calculated</td>
</tr>
<tr>
<td>1 kg</td>
<td></td>
<td>given</td>
</tr>
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</table>

APPENDIX A: DATA & SOURCES  Manufacturing Data (continued)

BRICK LCA
## AVERAGE WAGES - MANUFACTURING

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Molders, Shapers, and Casters, Except Metal and Plastic</td>
<td>51-9195</td>
<td>7.03% 3160</td>
<td>$28,830 [m]</td>
<td>$91,102,800</td>
<td>$27,010</td>
<td>$85,351,600</td>
<td>$28,160</td>
<td>$88,985,600</td>
<td>$24,910</td>
<td>$78,715,600</td>
<td></td>
</tr>
<tr>
<td>Extruding, Forming, Pressing, and Compacting Machine Setters, Operators, and Tenders</td>
<td>51-9041</td>
<td>5.52% 2480</td>
<td>$29,710 [m]</td>
<td>$73,680,800</td>
<td>$33,470</td>
<td>$83,005,600</td>
<td>$28,990</td>
<td>$71,895,200</td>
<td>$27,590</td>
<td>$68,423,200</td>
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</tr>
<tr>
<td>Furnace, Kiln, Oven, Drier, and Kettle Operators and Tenders</td>
<td>51-9051</td>
<td>5.52% 2140</td>
<td>$31,120 [m]</td>
<td>$66,596,800</td>
<td>$31,310</td>
<td>$67,003,400</td>
<td>$29,700</td>
<td>$63,558,000</td>
<td>$33,370</td>
<td>$71,411,800</td>
<td></td>
</tr>
<tr>
<td>First-Line Supervisors/Managers of Production and Operating Workers</td>
<td>51-1011</td>
<td>4.63% 2080</td>
<td>$52,060 [m]</td>
<td>$108,284,800</td>
<td>$50,030</td>
<td>$104,062,400</td>
<td>$47,760</td>
<td>$101,672,000</td>
<td>$53,690</td>
<td>$111,765,200</td>
<td></td>
</tr>
<tr>
<td>Inspectors, Testers, Sorters, Samplers, and Weighers</td>
<td>51-9061</td>
<td>3.98% 1790</td>
<td>$33,280 [m]</td>
<td>$59,571,200</td>
<td>$35,520</td>
<td>$63,580,800</td>
<td>$31,390</td>
<td>$56,188,100</td>
<td>$32,680</td>
<td>$58,497,200</td>
<td></td>
</tr>
<tr>
<td>Helpers--Production Workers</td>
<td>51-9198</td>
<td>3.65% 1640</td>
<td>$25,190 [m]</td>
<td>$41,311,600</td>
<td>$26,030</td>
<td>$42,689,200</td>
<td>$24,010</td>
<td>$39,376,400</td>
<td>$21,550</td>
<td>$35,342,000</td>
<td></td>
</tr>
<tr>
<td>First-Line Supervisors/Managers of Production and Operating Workers</td>
<td>51-9061</td>
<td>3.98% 1790</td>
<td>$33,280 [m]</td>
<td>$59,571,200</td>
<td>$35,520</td>
<td>$63,580,800</td>
<td>$31,390</td>
<td>$56,188,100</td>
<td>$32,680</td>
<td>$58,497,200</td>
<td></td>
</tr>
<tr>
<td>Team Assemblers</td>
<td>51-2092</td>
<td>3.88% 1520</td>
<td>$26,310 [m]</td>
<td>$39,991,200</td>
<td>$29,610</td>
<td>$45,007,200</td>
<td>$26,000</td>
<td>$39,520,000</td>
<td>$26,680</td>
<td>$40,553,600</td>
<td></td>
</tr>
<tr>
<td>Mixing and Blending Machine Setters, Operators, and Tenders</td>
<td>51-9023</td>
<td>3.38% 1520</td>
<td>$31,400 [m]</td>
<td>$47,728,000</td>
<td>$40,390</td>
<td>$61,392,800</td>
<td>$30,980</td>
<td>$47,089,600</td>
<td>$32,970</td>
<td>$50,114,400</td>
<td></td>
</tr>
<tr>
<td>Machinists</td>
<td>51-1011</td>
<td>3.38% 1520</td>
<td>$31,400 [m]</td>
<td>$47,728,000</td>
<td>$40,390</td>
<td>$61,392,800</td>
<td>$30,980</td>
<td>$47,089,600</td>
<td>$32,970</td>
<td>$50,114,400</td>
<td></td>
</tr>
<tr>
<td>Painters, Coating, and Decorating Workers</td>
<td>51-9123</td>
<td>2.07% 930</td>
<td>$24,350 [m]</td>
<td>$39,991,200</td>
<td>$22,270</td>
<td>$20,711,100</td>
<td>$22,770</td>
<td>$21,176,100</td>
<td>$24,900</td>
<td>$23,157,000</td>
<td></td>
</tr>
<tr>
<td>Crushing, Grinding, and Polishing Machine Setters, Operators, and Tenders</td>
<td>51-9121</td>
<td>2.00% 900</td>
<td>$27,570 [m]</td>
<td>$42,689,200</td>
<td>$26,840</td>
<td>$25,776,000</td>
<td>$26,960</td>
<td>$24,264,000</td>
<td>$28,600</td>
<td>$25,776,000</td>
<td></td>
</tr>
<tr>
<td>Cutting and Slicing Machine Setters, Operators, and Tenders</td>
<td>51-9021</td>
<td>1.98% 890</td>
<td>$31,530 [m]</td>
<td>$28,061,700</td>
<td>$30,100</td>
<td>$26,789,000</td>
<td>$30,110</td>
<td>$26,797,900</td>
<td>$38,490</td>
<td>$34,256,100</td>
<td></td>
</tr>
<tr>
<td>Packaging and Filling Machine Operators and Tenders</td>
<td>51-9011</td>
<td>0.87% 390</td>
<td>$29,000 [m]</td>
<td>$11,310,000</td>
<td>$31,390</td>
<td>$12,242,100</td>
<td>$28,620</td>
<td>$11,161,800</td>
<td>$23,440</td>
<td>$9,141,600</td>
<td></td>
</tr>
<tr>
<td>Grinding and Polishing Workers</td>
<td>51-9022</td>
<td>0.82% 370</td>
<td>$27,900 [m]</td>
<td>$10,323,000</td>
<td>$10,704,100</td>
<td>$26,710</td>
<td>$9,882,700</td>
<td>$28,990</td>
<td>$11,267,100</td>
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<td></td>
</tr>
<tr>
<td>Overall Wages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BRICK LCA  APPENDIX A: DATA & SOURCES  Transportation Data

Transportation (Common Clay)

Transportation distances from calculations (in the case of site-specific data) and general industry sources (in the case of general industry data). Economic data from "The Geography of Transportation Systems" (see source [1] below) and the "U Ship Price Estimator" (see source [8] below). Environmental (emission) data calculated based upon vehicle miles traveled and emission factors from the EPA, assuming a fuel efficiency of 6mpg for a laden semi truck. Ethical data from the U.S. Bureau of Labor Statistics, as follows: wage data based upon "Truck Drivers, Heavy and Tractor-Trailer" (see references [9, 10] below); injury/illness and fatality data based upon "General Freight Trucking, Long Distance" (see references [11, 12] below).

### Site-Specific Data (Brick to Cincinnati, Ohio)

<table>
<thead>
<tr>
<th>Units</th>
<th>Extraction to manufacture</th>
<th>Assembly to assembly</th>
<th>Assembly to disposal</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q</td>
<td>Source</td>
<td>Q</td>
<td>Source</td>
</tr>
<tr>
<td>Type of transport</td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ECONOMIC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per unit cost</td>
<td>$ / ton-mile</td>
<td>$0.251</td>
<td>[1]</td>
<td>$0.251</td>
</tr>
<tr>
<td>Total cost - source 1</td>
<td>$ / ton</td>
<td>$0.00</td>
<td>$30.87</td>
<td>calc.</td>
</tr>
<tr>
<td>Total cost - source 2</td>
<td>$ / ton</td>
<td>N/A</td>
<td>$62.50</td>
<td>[8]</td>
</tr>
<tr>
<td><strong>ENVIRONMENTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHG emissions</td>
<td>lbs CO2-e / truck load</td>
<td>0</td>
<td>[6,7]</td>
<td>420.3</td>
</tr>
<tr>
<td>Energy use</td>
<td>MMBTU / ton</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
</tr>
<tr>
<td>Water use</td>
<td>gal / ton</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
</tr>
<tr>
<td><strong>ETHICAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury / illness rate</td>
<td>cases per 100 employees</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
</tr>
<tr>
<td>relative to all occupations</td>
<td>%</td>
<td>NO DATA</td>
<td>148.6</td>
<td>[11]</td>
</tr>
<tr>
<td>Fatalities per 100,000 employees</td>
<td>%</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
</tr>
<tr>
<td>Annual wage (Cincinnati)</td>
<td>$ / yr</td>
<td>57.25</td>
<td>[7]</td>
<td></td>
</tr>
<tr>
<td><strong>TRANSPORT INFO</strong></td>
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</table>

### General Industry Data (Brick in the U.S.)

<table>
<thead>
<tr>
<th>Units</th>
<th>Extraction to manufacture</th>
<th>Assembly to assembly</th>
<th>Assembly to disposal</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q</td>
<td>Source</td>
<td>Q</td>
<td>Source</td>
</tr>
<tr>
<td><strong>ECONOMIC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per unit cost</td>
<td>$ / ton-mile</td>
<td>$0.251</td>
<td>[1]</td>
<td>$0.251</td>
</tr>
<tr>
<td>Total cost - source 1</td>
<td>$ / ton</td>
<td>$50.20</td>
<td>calc.</td>
<td>$12.55</td>
</tr>
<tr>
<td>Total cost - source 2</td>
<td>$ / ton</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>ENVIRONMENTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy use</td>
<td>MMBTU / ton</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
</tr>
<tr>
<td>Water use</td>
<td>gal / ton</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
</tr>
<tr>
<td><strong>ETHICAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury / illness rate</td>
<td>cases per 100 employees</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
</tr>
<tr>
<td>relative to all occupations</td>
<td>%</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
</tr>
<tr>
<td>Fatalities per 100,000 employees</td>
<td>%</td>
<td>NO DATA</td>
<td>NO DATA</td>
<td>NO DATA</td>
</tr>
<tr>
<td>Annual wage (Cincinnati)</td>
<td>$ / yr</td>
<td>65.16</td>
<td>[9]</td>
<td></td>
</tr>
</tbody>
</table>

### Sources


### Environmental Impacts - Diesel Fuel

- **Diesel**
  - Btu per mile: 22.2 lbs CO2-e [6]
  - Fuel cost: 19.4 lbs CO2-e [6]
- **Semi truck efficiency**
  - CO2 per mile: 6 mpg [7]
- **CO2 per mile**
  - Emission: 3.7 lbs CO2 per mile

### Conversions

- 1 semi = 12 pallets brick
- 1 pallet brick = 480 bricks
- 1 brick = 4.5313 lbs
- 1 pallet bricks = 2175 lbs
- 1 pallet brick = 1.6875 tons
- 1 semi = 13.05 tons
**Composition of a Brick Wall**

<table>
<thead>
<tr>
<th>Component</th>
<th>% Source</th>
<th>Quantity Units</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composition of Brick Wall</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>By Volume</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard brick</td>
<td>71.07%</td>
<td>[c] 0.2677 c.f. brick</td>
<td>[d]</td>
</tr>
<tr>
<td>Mortar (type N)</td>
<td>28.93%</td>
<td>[c] 0.1090 c.f. mortar</td>
<td>[d]</td>
</tr>
<tr>
<td><strong>By Weight</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard brick</td>
<td>68.59%</td>
<td>[e] 0.0161 tons / s.f. wall</td>
<td>[e]</td>
</tr>
<tr>
<td>Mortar (type N)</td>
<td>31.41%</td>
<td>[e] 0.0074 tons / s.f. wall</td>
<td>[e]</td>
</tr>
</tbody>
</table>

**Composition of Brick**

| By Material Used in Production | | | |
| Clay & bottom ash | 85% | [a] 1700 lbs / ton | calc. |
| Water | 15% | [b] 300 lbs / ton | calc. |
| Manganese | negligible | [c, d] 0 lbs / ton | calc. |

**By Mass**

| Bottom ash | 0.08% | [f] 1.6 lbs / ton | calc. |

**Composition of Type N Mortar by Volume**

| Portland cement | 9.4% | 3.375 c.f. | [c] |
| Hydrated lime | 9.4% | 3.375 c.f. | [c] |
| Sand | 56.3% | 20.25 c.f. | [c] |
| Water | 28.0% | 9.00 c.f. | calc. |
| TOTAL | 100.0% | 36.00 c.f. | calc. |

**Composition of Portland Cement**

| Limestone | 71.7% | 1.17 kg | [g] |
| Cement rock / marl | 12.9% | 0.21 kg | [g] |
| Clay | 3.7% | 0.06 kg | [g] |
| Shale | 3.1% | 0.05 kg | [g] |
| Sand | 2.5% | 0.04 kg | [g] |
| Slag | 1.2% | 0.02 kg | [g] |
| Iron / iron ore | 0.6% | 0.01 kg | [g] |
| Fly ash | 0.6% | 0.01 kg | [g] |
| Bottom ash | 0.6% | 0.01 kg | [g] |
| Foundry sand | 0.2% | 0.004 kg | [g] |
| Slate | 0.1% | 0.001 kg | [g] |
| Gypsum | 2.9% | 0.048 kg | [g] |
| TOTAL | 100.0% | 1.835 kg | calc. |

**End of Life Trajectories**

| Reuse | 25% | [f] 500 lbs / ton | calc. |
| Recycle | 49% | [f, h] 975 lbs / ton | calc. |
| Landfill | 26% | [f, h] 525 lbs / ton | calc. |
| TOTAL | 100% | | |

**Sources**

[d] calculated based upon data from R.S. Means (www.meanscostworks.com)
[e] calculated based upon data from R.S. Means (www.meanscostworks.com) and http://www.reade.com/Particle_Briefings/spec_gra2.html
[f] BEES 4.0, “Generic Brick and Mortar”
[g] BEES 4.0, “Generic Concrete Products with Portland Cement”
[h] utilizes a 65% recovery rate of daily infeed, based upon data from H. Hafler & Sons, http://www.hafners.com. Further research is needed to determine in this rate is typical.
Comparison to EIO-LCA: Economic Activity & GHG Emissions

**ECONOMIC ACTIVITY**

<table>
<thead>
<tr>
<th></th>
<th>This Analysis</th>
<th>Cost (US $ per ton)</th>
<th>% of total</th>
<th>Cost without Const., EOL, or Transp.</th>
<th>% of total</th>
<th>Economic Activity (millions of $)</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction</td>
<td></td>
<td>$44.81</td>
<td>5.9%</td>
<td>$44.81</td>
<td>29.8%</td>
<td>0.037</td>
<td>2.8%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td></td>
<td>$105.62</td>
<td>14.0%</td>
<td>$105.62</td>
<td>70.2%</td>
<td>1.033</td>
<td>78.2%</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td>$526.88</td>
<td>69.8%</td>
<td>$526.88</td>
<td>34.4%</td>
<td>135.00</td>
<td>70.6%</td>
</tr>
<tr>
<td>End of Life</td>
<td></td>
<td>$11.84</td>
<td>1.6%</td>
<td>$11.84</td>
<td>0.8%</td>
<td>135.00</td>
<td>0.0%</td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td>$65.16</td>
<td>8.6%</td>
<td>$65.16</td>
<td>4.4%</td>
<td>135.00</td>
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<td><strong>1321</strong></td>
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**EIO-LCA**

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<th>% of total</th>
<th>Cost without Const., EOL, or Transp.</th>
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<th>Economic Activity (millions of $)</th>
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**GREENHOUSE GAS EMISSIONS**

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<th>Emissions (metric tons CO2-e)</th>
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<th>Emissions without Power Gen.</th>
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