LIFE CYCLE ASSESSMENT of a BRICK BEARING WALL
Using Longworth Hall, Cincinnati, Ohio, as a point of departure

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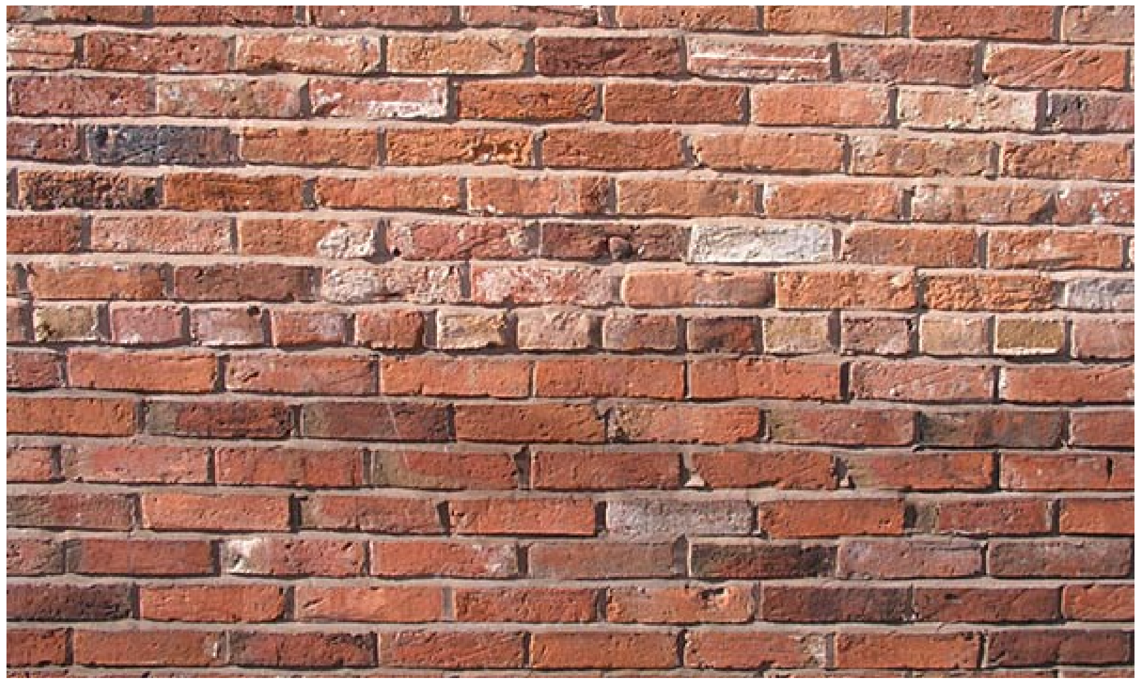
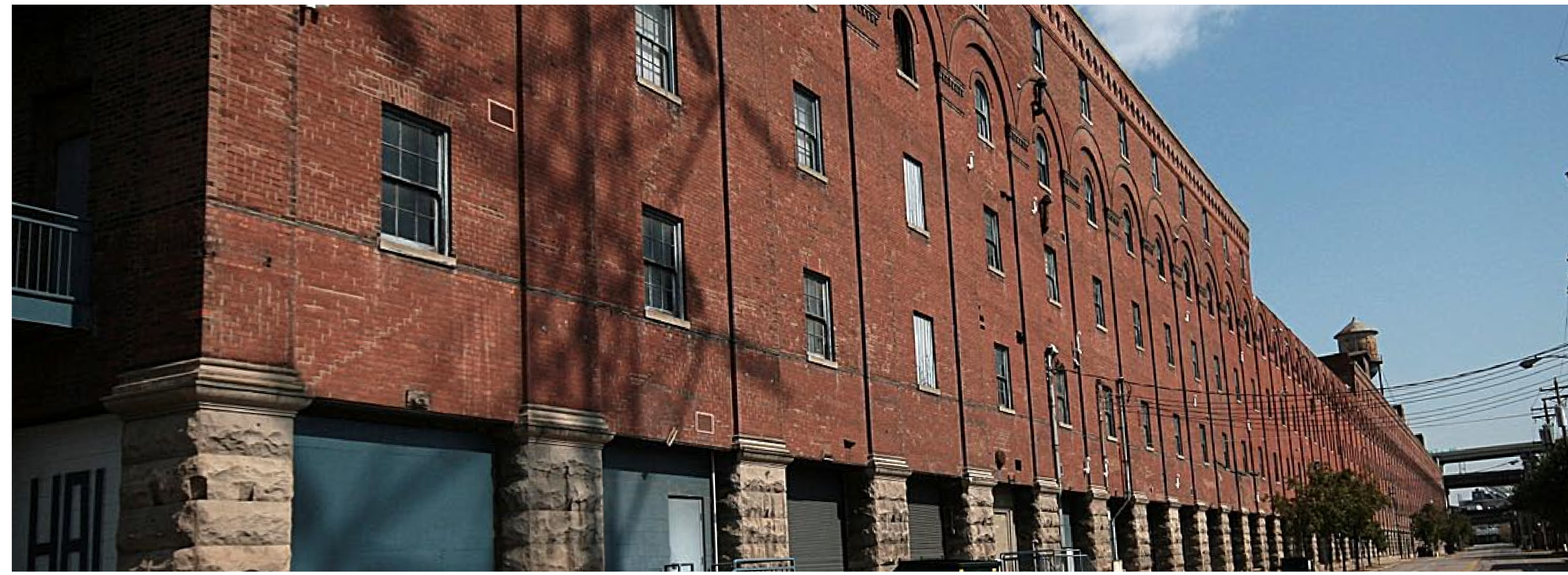




Longworth Hall, Cincinnati, Ohio // SOURCE

CONTENTS

INTRODUCTION & LCA GOALS

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 knows 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.[2] It is listed on the National Registry of Historic Places,[3] and is currently used as an office building. It was selected because of the author's personal fondness for the building,[4] 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.

1. E-mail: carlsterner@gmail.com

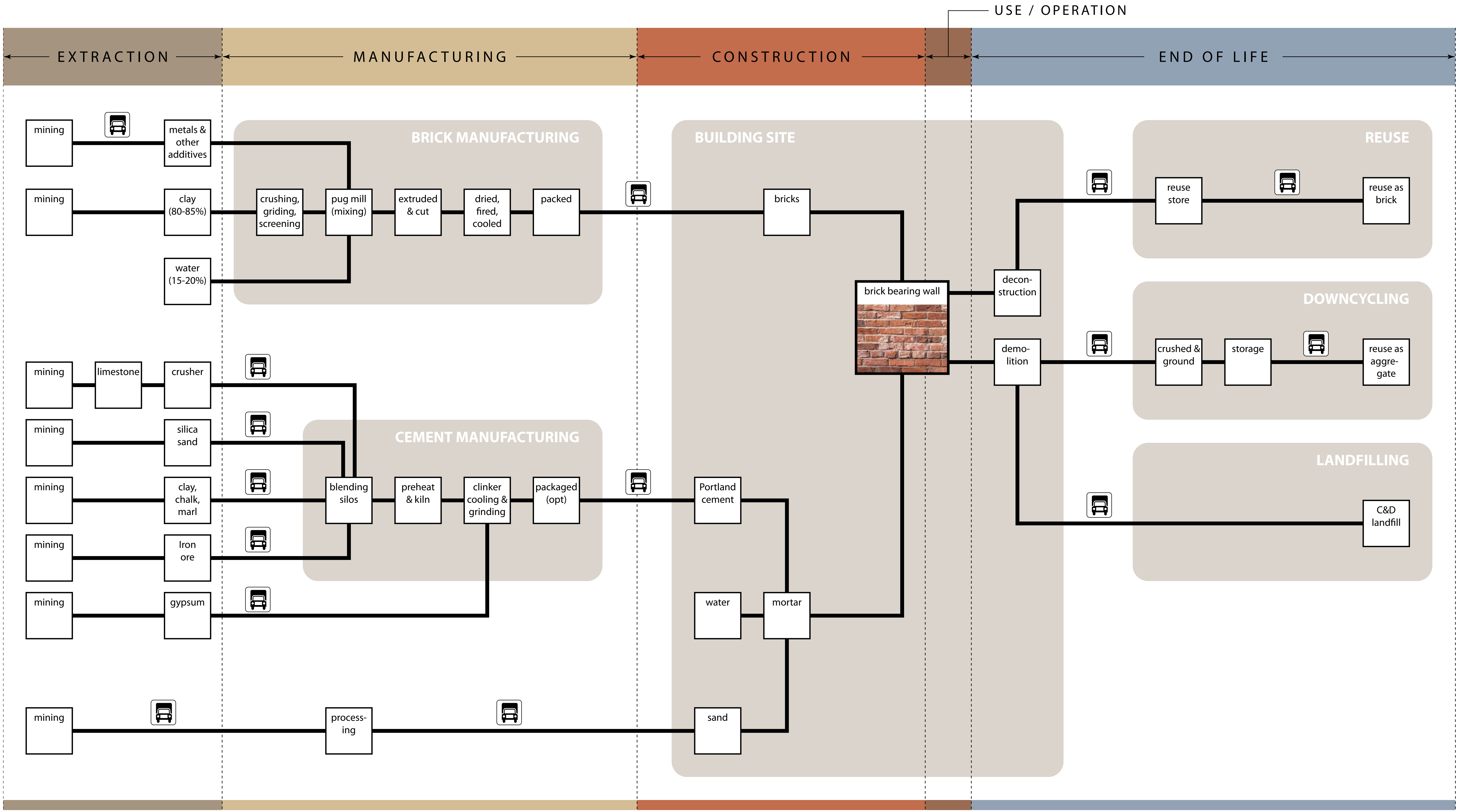
2. Longworth Hall website, "A Bit of History," http://www.longworthhall.com/about.html.

3. National Register of Historic Places, "B&O Freight Terminal," http://nrhp.focus.nps.gov/.

4. The author studied at the University of Cincinnati, and visited Longworth Hall on numerous occasions.

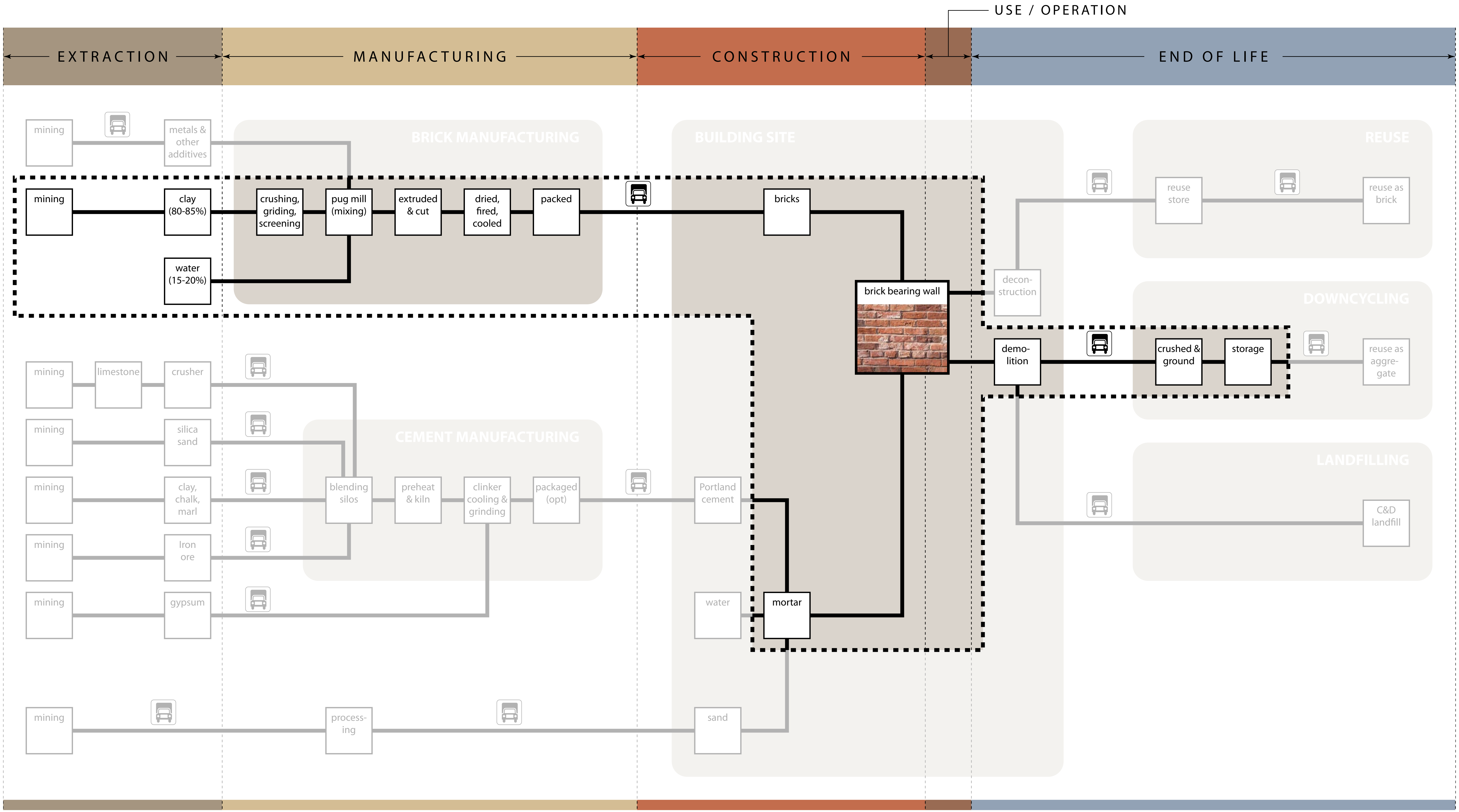
BRICK LCA MATERIAL FLOW DIAGRAM

This analysis looks at the economic, environmental, and ethical impacts of a brick bearing wall throughout its entire lifecycle—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 landfilling. 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.).



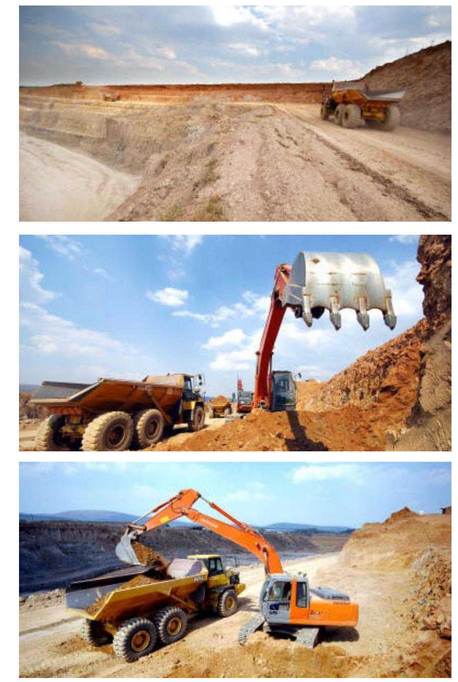
BRICK LCA SCOPE OF ANALYSIS

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.

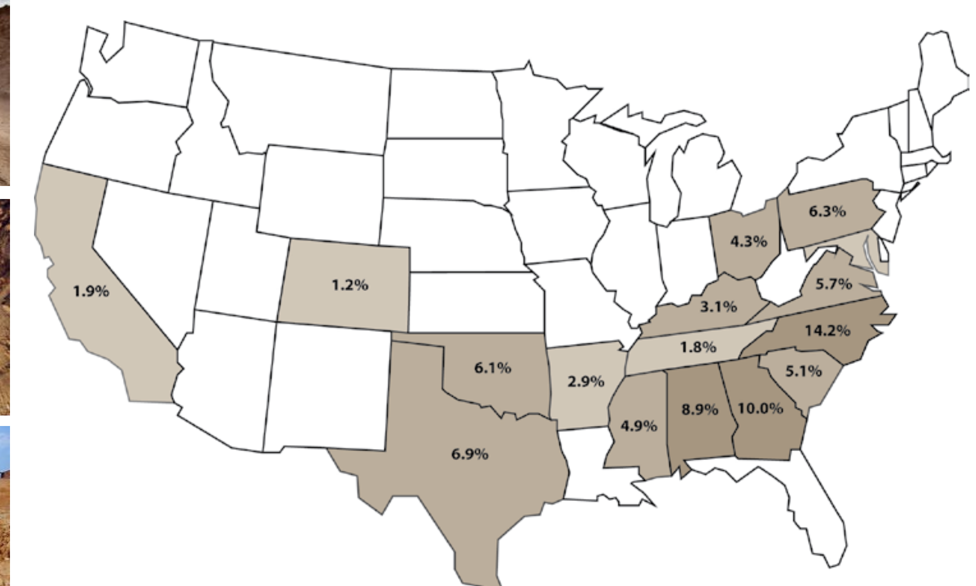


Princeton Quarry, North Carolina // Google Maps, www.google.com/maps

Stancills Clay Mine, Maryland // http://catherinewhite.com/rough-ideas/pottery/2008/10/



clay mining // www.nylstene.co.za/Gallery/body_gallery.html



U.S. Clay Production by State // data from U.S. Geological Survey (USGS 2010)

ECONOMIC

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.[1] According to Calkins (2010), clay quarries are typically "located adjacent to or within a few miles of the brick manufacturing facility […]."[2] Research suggests that quarries are often owned and operated by the same companies that manufacture the brick.[3]

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.[4]

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,[5] and the annual production value of common clay is $12.9 million.[6]

ENVIRONMENTAL

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.[7]

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;[8] clay likely emits less given the processes involved.

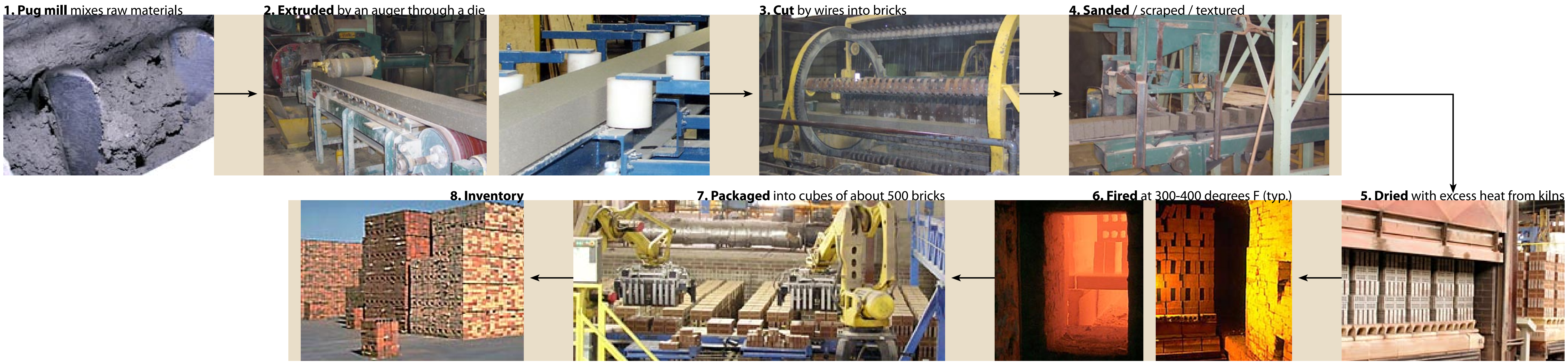
Water is used both for controlling dust at mines and for processing clay prior to shipping (which can include slurrying). Dust control measures use about 1-6 gallons of water per ton. Processing varies depending upon end use, but a rough figure is ~2,000 gallons per ton of finished product.[9] It is not clear whether this water is reused.

ETHICAL

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).[10] 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.[11]

Miners appear to be paid a fair wage. In the Cincinnati area, the average salary is $41,922—99% of the local average salary.[12] (This is an industry-wide average, including all of the workers in the "Non-metallic Mineral Mining and Quarrying" sector.) However, the wages are not proportional to the risk, suggesting that the occupation is at least somewhat exploitative.

1. USGS, "Mineral Commodity Summary: Clays," 44-45.
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."
4. USGS, *2008 Minerals Yearbook*, 18.21.
5. NCGS, "Mineral Resources."
6. National Mining Association, "Mining in North Carolina, 2004."
7. Calkins, *Materials for Sustainable Sites*, 182.
8. NREL, U.S. Life-Cycle Inventory Database, "Limestone, at mine."
9. Mavis, "Water Use in Industries," 50.
10. U.S. BLS, "2009 CFOI."
11. Calkins, *Materials for Sustainable Sites*, 182.
12. See Appendix A for calculations & sources.



Images 1, 2, 3 and 4 from: http://catherinewhite.com/rough-ideas/pottery/2008/10. // Images 1, 2b, 5, 6, 7 and 8 from www.glengerybrick.com. // Images 2a, 3 and 4 from www.umich.edu/~bricks/brickwebsite

METHODOLOGY

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.

ENVIRONMENTAL & ECONOMIC

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 CO_2e 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]

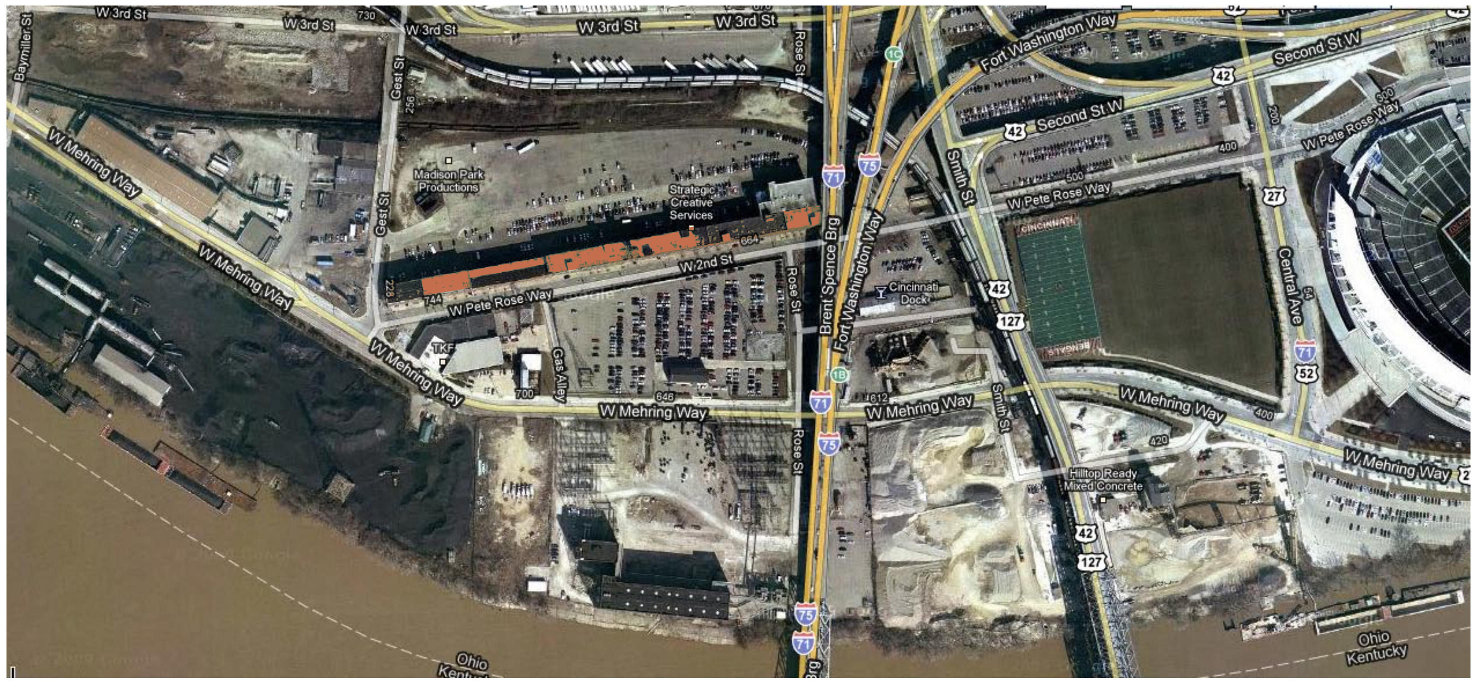
ETHICAL

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.

The illness / injury rate for brick and structural clay tile manufacturing is 7.0 per 100 employees, which is well above the average of 3.7 across all industries.[7] A specific fatality rate for brick manufacturing was unavailable; the fatality rate for the manufacturing sector overall is 2.2 per 100,000 employees, which is 66.7% of the average of 3.3 across all industries.[8]

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).
2. Amato, et al., "Brick Manufacturing Process."
3. U.S. DOE, Industrial Assessment Centers Database.
4. For calculations, see Appendix A.
5. Natural gas emission data from U.S. DOE, "Fuel Emission Coefficients." Electricity emission data from U.S. EPA, "Greenhouse Gas Emission Factors."
6. U.S. DOE, Industrial Assessment Centers Database.
7. U.S. BLS, "Incidence Rates of Nonfatal Occupational Injuries and Illnesses, 2008."
8. U.S. BLS, "2009 CFOI."
9. Wage data from the U.S. Bureau of Labor Statistics. See Appendix A for calculations & sources.



Longworth Hall, Cincinnati, Ohio // Google Maps, www.google.com/maps

Longworth Hall under construction // all construction photos from www.longworthhall.com/about

ECONOMIC

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.

Item	Cost per s.f. wall[1]	Cost per ton brick[2]
Bare material cost (brick & mortar, including waste)	$2.90	$123.82
Labor cost	$6.08	$259.60
Total bare cost	$8.98	$383.42
Total cost (including overhead & profit)	$12.34	$526.88

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.

ENVIRONMENTAL

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.[3] Construction wastes are often landfilled, although brick waste can also be recycled or reused (see "End of Life" for more).

Necessary equipment includes hand trowels, scaffolding, and possibly mechanical equipment for mixing mortar. Both of the former are people-powered, will be reused when construction is over, and are not associated with any on-site emissions. The latter (equipment for mixing mortar) likely has some CO_2 emissions associated with it, but data was not found at the time of this writing. (The emissions would not likely have a large impact on the overall Life Cycle Assessment figures.)

ETHICAL

Bricks are installed by a team consisting of (3) bricklayers and (2) bricklayer helpers.[4] 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.[5] The illness / injury rate is 4.6 cases per 100 employees (124.3% of the average across all industries),[6] and fatality rates are 18.3 per 100,000 employees (554.5% of average).[7] 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.[8] 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.

1. RSMeans, "Reference Tables: Crews," Crew D-8, 685.
2. Calculated. For calculations, see Appendix A.
3. RSMeans, "Reference Tables: Clay Unit Masonry," 772.
4. RSMeans, "Reference Tables: Crews," Crew D-8, 685.
5. U.S. BLS, "Occupational Employment and Wages, May 2009."
6. U.S. BLS, "Incidence Rates of Nonfatal Occupational Injuries and Illnesses, 2008."
7. U.S. BLS, "2009 CFOI."
8. Calkins, *Materials for Sustainable Sites*, 186; citing others (ATSDR 2003b, and Demkin 1998b).

Longworth Hall, ca. 1904 // www.longworthhall.com

Longworth Hall, Cincinnati, present day // www.longworthhall.com

Longworth Hall, "Eddy's Belgian Bistro" // photo by Eleanor Howell, http://www.flickr.com/photos/eleanorh/2748911948/

LIFESPAN OF BUILDING 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.[1] 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."[2]

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.

MAINTENANCE

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.[3]

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 stilled 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.[4]

BUILDING OPERATION

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.[5]

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.[6]

1. Joseph Lstiburek, "Increasing the Durability of Building Constructions."

2. Ibid.

3. Brick Industry Association. "Maintenance of Brick Masonry."

4. Ibid.

5. Brick Industry Association. "Passive Solar Heating with Brick Masonry."

6. A 2009 study of historic buildings by the Athena Sustainable Materials Institute found that, property 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," 21.

C&D Landfill // http://ze-gen.com/rethink/harnessing-the-energy-of-your-home%E2%80%99s-renovation-debris

H. Hafner & Sons, Inc., Cincinnati, Ohio // Google Maps, www.google.com/maps

Building Value retail outlet // www.soapboxmedia.com/devnews/1117buildingvalue.aspx

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, landfilling appears 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."[4] 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.

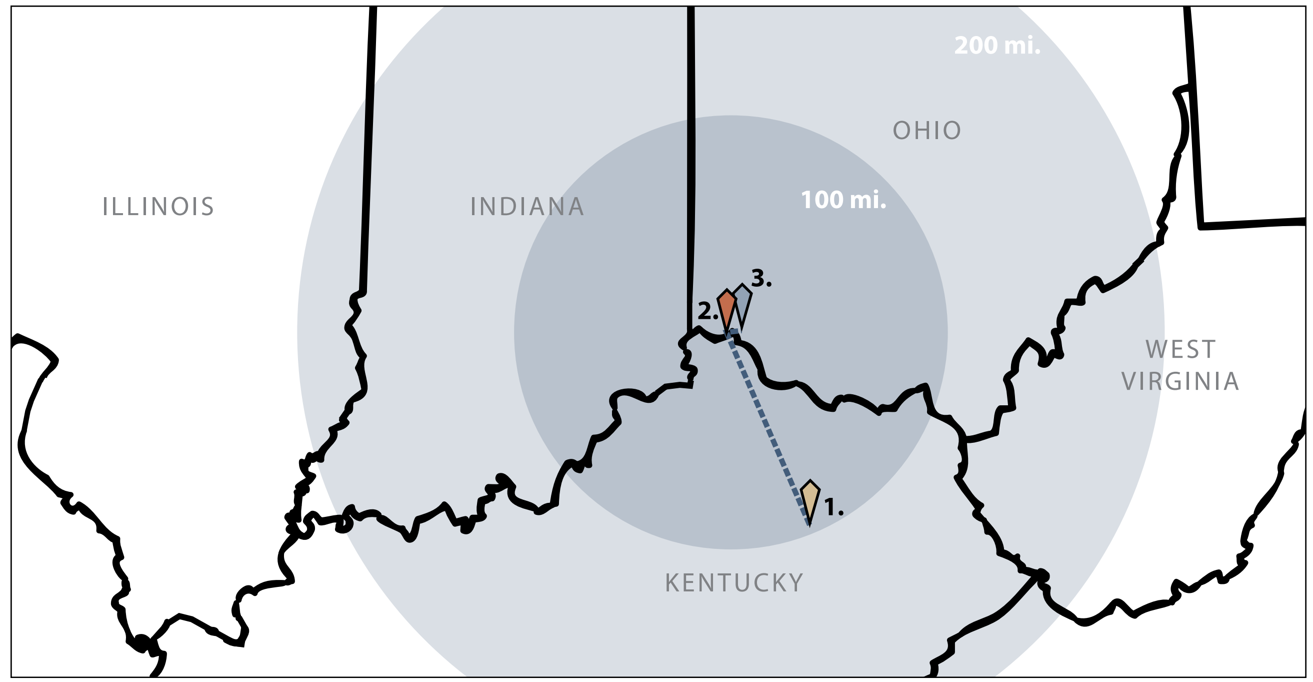
There are several resources for building reuse in Cincinnati. Building Value is a building re-use store that accepts brick for reuse. In addition, Building Value provides "on-the-job training […] to move people with workforce disadvantages into construction and retail careers."[6] Similarly, Covington Reuse Center accepts brick, and hires and trains people with "workplace disadvantages."[7] 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.

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."
4. U.S. BLS, "Occupational Employment and Wages, May 2009."
5. Quarry News, "Cincinnati Recycler Prefers Keestrack Destroyer."
6. Building Value, "Job Training."
7. Covington Re-Use Center website.

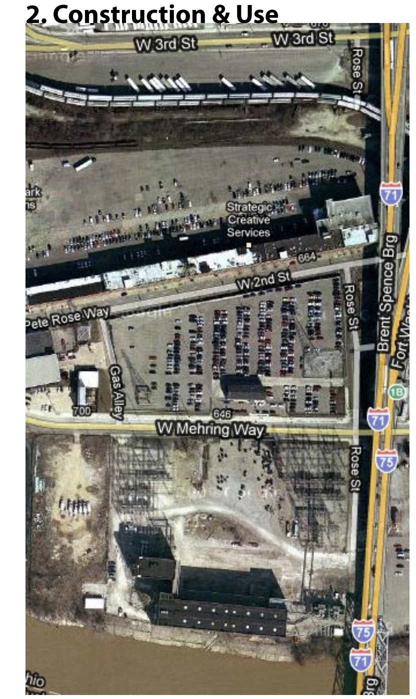
1.Extraction & Manufacturing

Princeton Quarry, North Carolina // Google Maps, www.google.com/maps



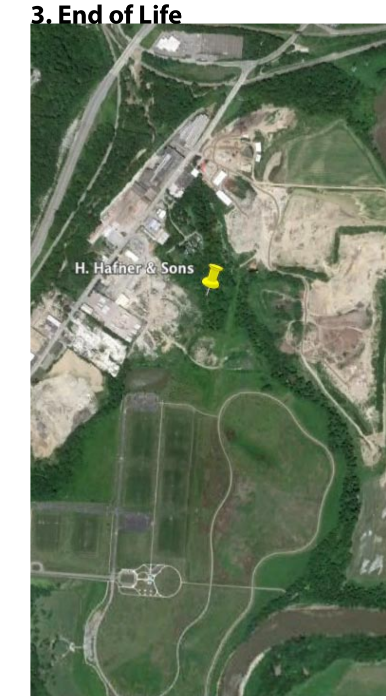
transportation map // Carl Sterner

2. Construction & Use



Longworth Hall // Google Maps, www.google.com/maps

3. End of Life



H. Hafner & Sons // Google Maps, www.google.com/maps

TRANSPORTATION DATA

Transportation figures are based upon Longworth Hall in Cincinnati, Ohio. Research indicates that these figures are slightly below average, but not atypical.

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

ENVIRONMENTAL

Assuming emissions of 22.2 lbs of CO_2 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 CO_2 per ton of bricks.[2] 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 CO_2 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.[3] 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.[4] 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.[5] 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.

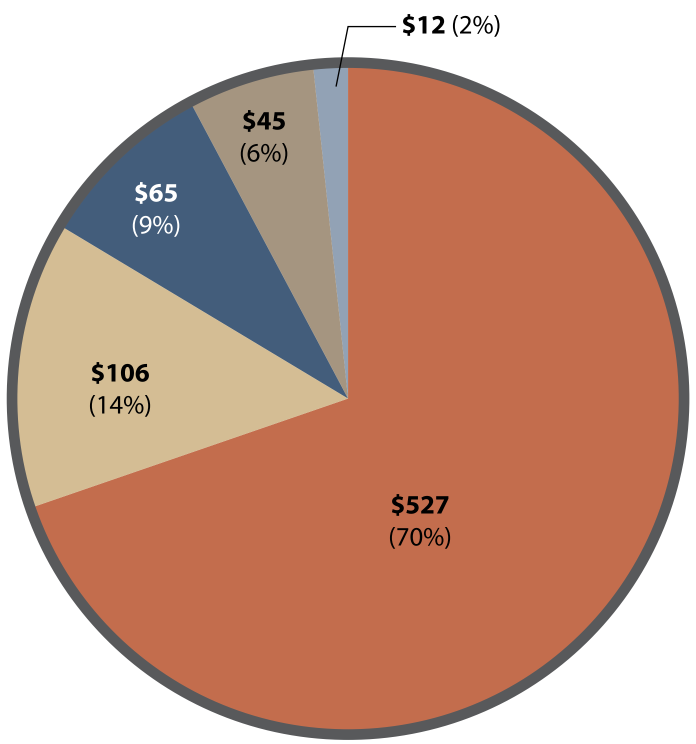
Truck drivers have very high rates of injury and illness, and are among the occupations with the highest fatality rates. The injury rate for truck drivers is 5.5 per 100 full-time employees, 148.6% higher than the average of 3.7 across all industries.[6] The fatality rate is 18.3 per 100,000 employees per year, 555% higher than the average of 3.3 across all industries.[7]

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.[8] Even so, the wages are is not proportional to the increased risks of injury and/or death.

1. Brick Industry Association, "Sustainability and Brick."
2. Data from: U.S. EPA, "Emission Facts;" Lawrence Livermore National Laboratory, "Lawrence Livermore National Lab, Navistar Work to Increase Semi-Truck Fuel Efficiency;" and Pioneer Sand Co., "Flagstone Wholesale." For complete calculations, assumptions, and sources, see Appendix A.
3. Hanson Brick and Tile, "Sustainable Development."
4. Boral Bricks, Inc., "Building With Brick."
5. U Ship website, Price Estimator.
6. U.S. BLS, "Incidence Rates of Nonfatal Occupational Injuries and Illnesses, 2008."
7. U.S. BLS, "2009 CFOI."
8. U.S. BLS, "Occupational Employment and Wages, May 2009."

BRICK LCA METRICS BY LIFE CYCLE STAGE

ECONOMIC INDICATORS



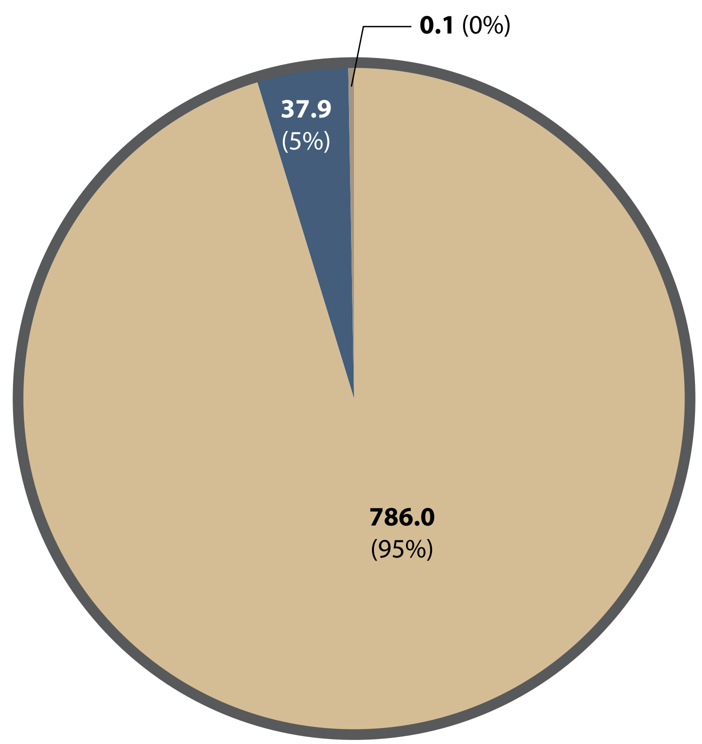
COST (US dollars per ton brick)

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.

ENVIRONMENTAL INDICATORS

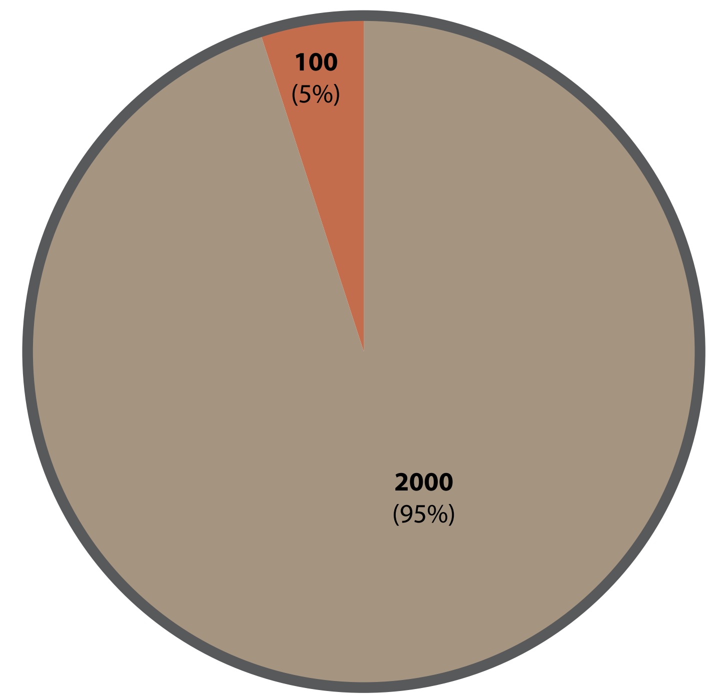


GREENHOUSE GAS EMISSIONS (lbs CO_2-e per ton brick)

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 CO_2-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.



WATER USE (gallons per ton brick)

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:

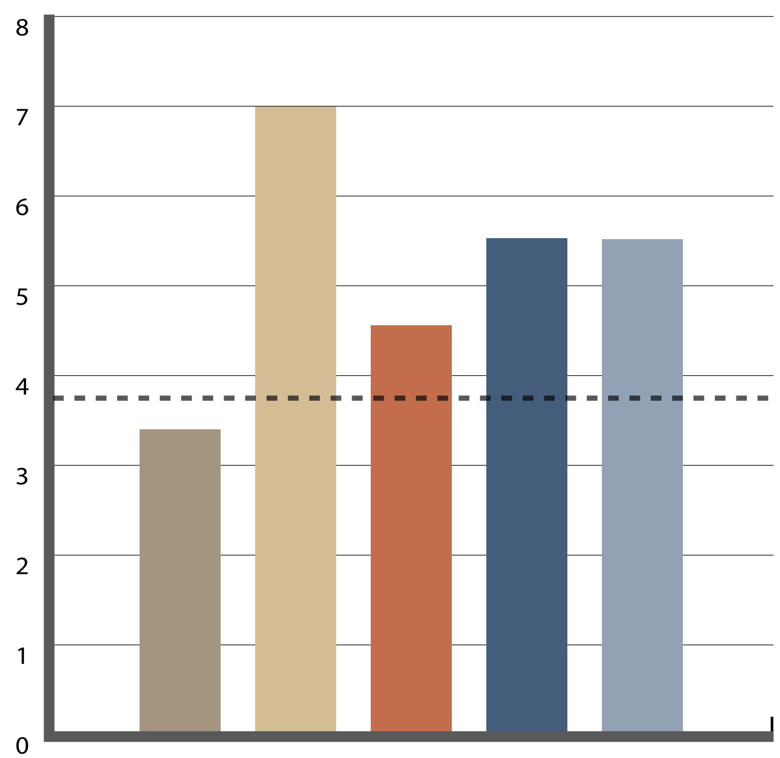
Land use impacts. Quarrying clay and construction of a building can disrupt habitat and contribute to soil erosion. However, clay mines are relatively shallow and are often reclaimed after use.

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.

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.

ETHICAL INDICATORS

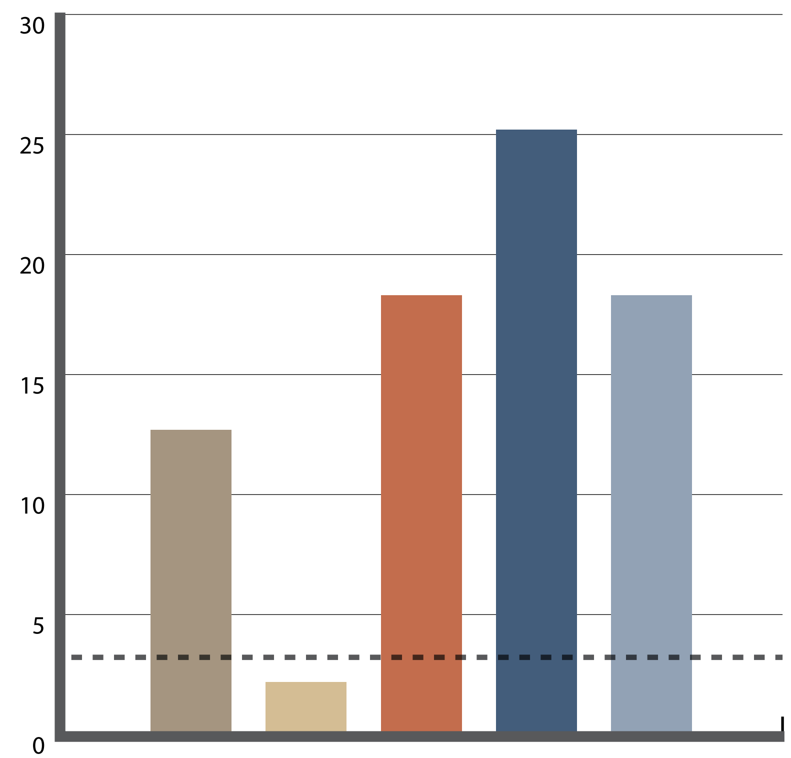


INJURY / ILLNESS RATE (cases per 100 employees)

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).



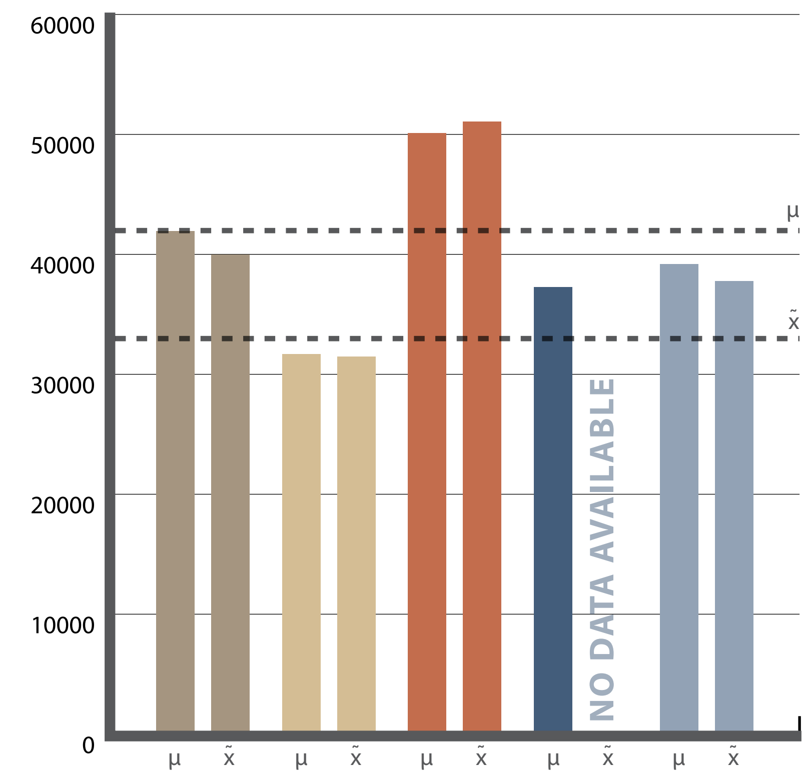
FATALITY RATE (cases per 100,000 employees)

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.



MEAN (μ) AND MEDIAN (x̃) ANNUAL WAGE ($ per year)

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.

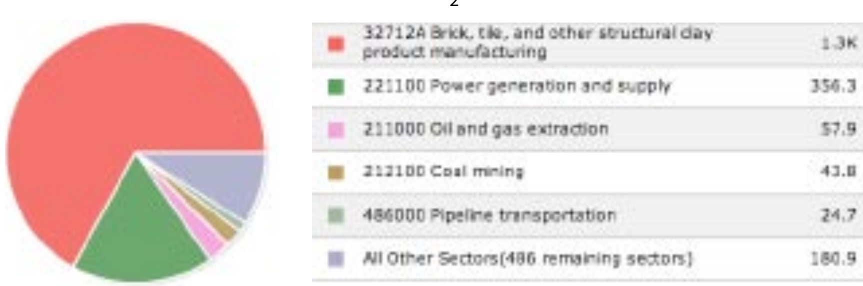
Mean and median annual wages do not appear to differ markedly in the sectors for which data was available.

This data is available in table form on page 17. For complete calculations, see Appendix A.

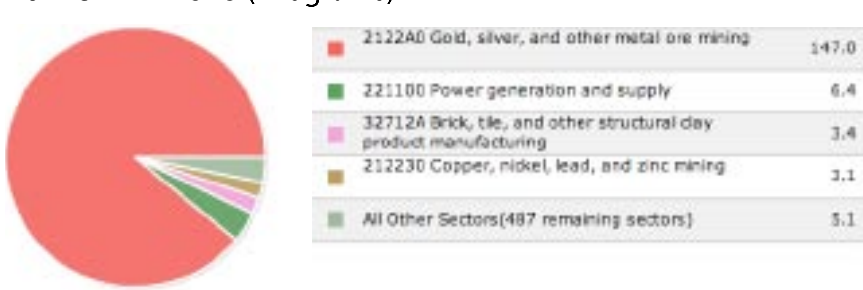
ECONOMIC ACTIVITY (millions of dollars)

ENERGY USE (millions of kWh)

GHG EMISSIONS (metric tons CO_2e)



TOXIC RELEASES (kilograms)



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-oriented 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 Melon 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.[4] 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"?)

	ECONOMIC ACTIVITY						GREENHOUSE GAS EMISSIONS					
	This Analysis				**EIOLCA**		**This Analysis**		**EIOLCA**			
	Cost (US $ per ton)	% of total	Cost without Const., EOL, or Transp.	% without Const., EOL, or Transp.	Economic Activity (millions of $)	% of total	GHG Emissions (lbs CO_2-e per ton)	% of total	GHG Emissions (metric tons CO_2-e)	% of total	GHG Emissions without Power Gen.	% without Power Gen.
Extraction	$44.81	5.9%	$44.81	29.8%	0.037	2.8%	0.10	0.0%	0.0	0.0%	0.0	0.0%
Manufacturing	$105.62	14.0%	$105.62	70.2%	1.033	78.2%	786.07	95.4%	1350.0	70.6%	1350.0	96.9%
Construction	$526.88	69.8%					0.00	0.0%				
End of Life	$11.84	1.6%					0.04	0.0%				
Transportation	$65.16	8.6%					37.88	4.6%	10.3	0.5%	10.3	0.7%
Power Generation & Supply Chain					0.04	3.0%			517.9	27.1%		
Other					0.211	16.0%			33.5	1.8%	33.5	2.4%
TOTALS	$754.31	100.0%	$150.43	100.0%	1.321	100.0%	824.10	100.0%	1911.7	100.0%	1393.8	100.0%

1. For more on BEES, see the National Institute of Standards and Technology (NIST), http://www.nist.gov/el/economics/BEESSoftware.cfm. For more on the Athena Impact Estimator, see the Athena Sustainable Materials Institute, http://www.athenasmi.org/tools/impactEstimator/.

2. Carnegie Mellon University, "About the EIO-LCA Method."

3. Carnegie Mellon University, "Approaches to Life Cycle Assessment."

4. For complete EIOLCA data, and a larger version of the comparison table, see page 28.

BRICK LCA CONCLUSIONS & RECOMMENDATIONS

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-trying 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. EIOLCA 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*.

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BRICK LCA APPENDIX A: DATA & SOURCES Overall LCA Data

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

Carl S. Sterner

		Extraction / Harvest		Manufacturing		Shipping / Transport		Construction		Operations		End of Life (Landfill)		TOTALS
Metric	Units	Quantity	Source	Quantity	Source	Quantity	Source	Quantity	Source	Quantity	Source	Quantity	Source	Quantity
ECONOMIC														
Material cost	$ / sq. ft. wall	NO DATA		NO DATA		NO DATA		$2.90	[1]			NO DATA		
	$ / ton	NO DATA		NO DATA		NO DATA		$123.82	calc.			NO DATA		
Labor cost	$ / sq. ft. wall	NO DATA		NO DATA		NO DATA		$6.08	[1]			NO DATA		
	$ / ton	NO DATA		NO DATA		NO DATA		$259.60	calc.			NO DATA		
Total cost	$ / sq. ft. wall	$1.05	calc.	$2.47	calc.	$1.53	calc.	$12.34	[1]			$0.28	calc.	$17.67
	$ / ton	$44.81	[14]	$105.62	calc.	$65.16	[24,25]	$526.88	calc.			$11.84	[32]	$754.31
ENVIRONMENTAL														
Emissions to air														
Total GHG emissions	lbs CO2e / ton	0.1022	[18]	786.07	calc.	37.88	[26,27,28]	NO DATA				0.0441	[33]	824.10
GHG emissions from electricity	lbs CO2e / ton			633.53	[22]			NO DATA				NO DATA		
GHG emissions from nat. gas	lbs CO2e / ton			152.54	[23]			NO DATA				NO DATA		
Energy use	MMBTU / ton	NO DATA		1.6667	[20]	NO DATA		NO DATA				NO DATA		
Electricity	MMBTU / ton	NO DATA		0.1207	[20]	NO DATA		NO DATA				NO DATA		
Natural gas	MMBTU / ton	NO DATA		1.3040	[20]	NO DATA		NO DATA				NO DATA		
Water use	gal / ton	2000	[19]	NO DATA		NO DATA		100	est.			NO DATA		2100
ETHICAL														**Averages**
Injury / illness rate	cases per 100 employees	3.4	[16]	7.0	[16]	5.5	[16]	4.6	[16]			5.5	[16]	5.2
relative to all occupations	%	91.9%	[16]	189.2%	[16]	148.6%	[16]	124.3%	[16]			148.6%	[16]	140.5%
Fatality rate	per 100,000 employees	12.7	[17]	2.2	[31]	18.3	[31]	18.3	[2]			25.2	[2]	15.34
relative to all occupations	%	384.8%	[2]	66.7%	[31]	554.5%	[31]	554.5%	[2]			763.6%		464.8%
Annual wage (Cincinnati)														
Mean	$ / yr	$41,922	calc.	$31,677	calc.	$39,180	[29]	$50,110	[2]			$37,290	[2]	$40,036
Median	$ / yr	$39,977	calc.	$31,483	calc.	$37,770	[29]	$51,070	[2]			NO DATA		$40,075
% of local avg. wage														
Mean	%	99%	calc.	75%	calc.	97.2%	[29]	118%	[2]			88.1%	[2]	95.5%
Median	%	121%	calc.	96%	calc.	118.7%	[29]	155%	[2]			NO DATA		122.6%

Sources

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[2] U.S. Bureau of Labor Statistics (www.bls.gov) [cfch0008.pdf]
[3] Meg Calkins, *Materials for Sustainable Sites* (Hoboken, NJ: John Wiley & Sons, 2009), 186.
[4] http://www.longworthhall.com/about.html
[5] http://wiki.answers.com/Q/What_is_the_weight_of_a_red_clay_brick_in_Kilograms
[6] http://en.howtopedia.org/wiki/How_to_Measure_the_Energy_Used_to_Fire_Clay_Bricks
[7] http://www.reade.com/Particle_Briefings/spec_gra2.html
[8] http://www.csgnetwork.com/brickgeninfocalc.html
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[10] http://www.umich.edu/~bricks/brickwebsite/setting_drying/setting_drying_page3.htm
[11] http://www.engineering.com/content/ContentDisplay?contentId=41005029; as quoted in Atish Bajpai, et al., "A Comparative Life Cycle
[12] http://wiki.answers.com/Q/How_many_bricks_in_a_pallet_of_brick
[13] http://answers.ask.com/Business/Other/how_much_does_a_pallet_of_bricks_cost
[14] Robert L. Vitra, "2008 Minerals Yearbook: Clay and Shale [Advance Release]" (U.S. Geological Survey, September 2010), http://minerals.usgs.gov/minerals/pubs/commodity/clays/myb1-2008-clays.pdf
[15] National Mining Association (NMA), "Mining in North Carolina, 2007" (http://www.nma.org/pdf/states/econ/nc.pdf)
[16] U.S. Bureau of Labor Statistics, "Incidence rates of nonfatal occupational injuries and illnesses by industry and case types, 2008" (http://www.bls.gov/iif/oshwc/osh/os/ostb2071.pdf)
[17] U.S. Bureau of Labor Statistics (www.bls.gov) [cfch0008.pdf]
[18] U.S. Life-Cycle Inventory Database, "Limestone, at mine," http://www.nrel.gov/lci/database/default.asp (accessed 26 September 2010)
[19] Jim Mavis, "Water Use in Industries of the Future," (U.S. Dept of Energy Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program, July 2003), http://www1.eere.energy.gov/industry/mining/pdfs/water_use_mining.pdf.
[20] U.S. Dept of Energy, Energy Efficiency and Renewable Energy, Industrial Technologies Program, "IAC Assessment Statistics" (2010)

Conversions				Source
1 sq. ft. wall	=	6.27	bricks (waste not included)	[8]
1 sq. ft. wall	=	7.09	bricks (including waste)	[1]
1 brick	=	0.03776042	c.f. brick	calculated
1 sq. ft. wall	=	0.26772135	c.f. bricks	calculated
1 c.f. wall	=	18.81	bricks	calculated
1 c.f. brick (no mortar)	=	26.48	bricks	calculated
1 brick	=	3	kg	[5],[6]
1 c.f. bricks	=	120	lbs	[7]
1 short ton	=	2000	lbs	given
1 ton	=	16.67	c.f. brick	calculated
1 ton brick	=	62.25	s.f. wall	calculated
1 ton	=	441.38	bricks	calculated
1000 bricks	=	10.3	c.f. mortar (waste included)	[1]
1 sq. ft. wall	=	7.09	bricks (including waste)	[1]
1 sq. ft. wall	=	0.109	c.f. mortar	calculated
1 c.f. mortar	=	135	lbs	[7]
1 m^3 mortar	=	1860	kg	[11]
1 ton	=	14.81	c.f. mortar	calculated
1 ton mortar	=	135.92	s.f. wall	calculated
1 ton	=	42.70	s.f. wall (brick + mortar)	calculated
1 kWh	=	3412.14	BTUs	[21]
1 MMBTU	=	1,000,000	BTUs	[21]

Sources
(http://iac.rutgers.edu/database/statistics/?STATE=&CENTER=&YEAR_limit=%3C%3D&YEAR=2010&SIC=&NAICS=327121&search=Search)
[21] http://www.energyvortex.com/energydictionary/british_thermal_unit_(btu)__mbtu__mmbtu.html
[22] U.S. EPA, http://cfpub.epa.gov/egridweb/ghg.cfm
[23] U.S. Energy Information Administration, http://www.eia.doe.gov/oiaf/1605/coefficients.html
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[26] U.S. EPA, http://www.epa.gov/otaq/climate/420f05003.htm
[27] Lawrence Livermore National Laboratory, https://www.llnl.gov/news/newsreleases/2010/NR-10-02-08.html
[28] http://www.pioneersand.com/wholesale/flagstone/flagstone.htm
[29] U.S. Bureau of Labor Statistics, http://data.bls.gov:8080/oes/datatype.do
[30] U.S. Bureau of Labor Statistics, http://www.bls.gov/iif/oshwc/osh/os/ostb2063.pdf
[31] U.S. Bureau of Labor Statistics, "Census of Fatal Occupational Injuries Charts, 1992-2009," http://www.bls.gov/iif/oshwc/cfoi/cfch0008.pdf
[32] H. Hafner & Sons, http://www.hafners.com/cincinnati-landscape-services/dumpster-rental.html
[33] U.S. EPA WARM calculator

Conversions						Source
1 metric ton	=	1.1023113	tons			given
Longworth Hall	=	4,250,000	bricks			[4]
Longworth Hall	=	160481.77	c.f. bricks			calculated
Longworth Hall	=	9628.91	tons brick			calculated
Longworth Hall	=	4410.35	tons mortar			calculated
1 s.f. wall	=	0.109	c.f. morta	28.93%	mortar by volume	
1 s.f. wall	=	0.26772135	c.f. brick	71.07%	brick by volume	
TOTAL	=	0.37672135		100.00%		
1 s.f. wall	=	0.0073575	tons mor	31.41%	mortar by weight	
1 s.f. wall	=	0.01606328	tons bric	68.59%	brick by weight	
TOTAL	=	0.02342078	tons			

Summary Table (Source for Charts)

	ECONOMIC		ENVIRONMENTAL				ETHICAL			
	Cost		**GHG Emissions**		**Water Use**		**Injury / Illness rate**	**Fatality Rate**	**Mean Annual Wage**	**Median Annual Wage**
	US $ per ton)	% of total	lbs CO_2-e per ton	% of total	gallons per ton	% of total	Cases per 100 emp.	Per 100,000 emp.	Cincinnati; 2010 US $	Cincinnati; 2010 US $
Extraction	$45	6%	0.10	0%	2000	95%	3.4	12.7	$41,922	$39,977
Manufacturing	$106	14%	786.07	95%	0	0%	7.0	2.2	$31,677	$31,483
Construction	$527	70%	0.00	0%	100	5%	4.6	18.3	$50,110	$51,070
Operation										
End of Life	$12	2%	0.04	0%	0	0%	5.5	25.2	$37,290	
Transportation	$65	9%	37.88	5%	0	0%	5.5	18.3	$39,180	$37,770
TOTAL / AVG.	$754	100%	824.10	100%	2100	100%	3.7	3.3	$42,340	$32,950

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	
Metric	Units	Quantity	Source
ECONOMIC			
Material cost	$ / ton		
Labor cost	$ / ton		
Total cost	$ / ton		
Total revenue	$ / ton	$44.81	[f]
ENVIRONMENTAL			
Emissions to air	Tons / ton		
Total GHG emissions	lbs CO2e / ton	0.1022	[g]
Energy use	MMBTU / ton		
Electrical	MMBTU / ton		
Natural Gas	MMBTU / ton		
Water use	gal / ton	2000	[h]
ETHICAL			
Injury / illness rate	cases per 100 employees	3.4	[a]
relative to all occupations	%	91.9%	
Fatality rate	per 100,000 / yr	12.7	[e]
relative to all occupations	%	384.8%	
Annual wage (Cincinnati)			
Mean	$ / yr	$41,922	calc.
Median	$ / yr	$39,977	calc.
% of local avg. wage			
Mean	%	99%	calc.
Median	%	121%	calc.

Sources

[a] U.S. Bureau of Labor Statistics, "Incidence rates of nonfatal occupational injuries and illnesses by industry and case types, 2008" (http://www.bls.gov/iif/oshwc/osh/os/ostb2071.pdf)
[b] NOT USED
[c] National Mining Association (NMA), "Mining in North Carolina, 2007" (http://www.nma.org/pdf/states/econ/nc.pdf)
[d] NOT USED
[e] U.S. Bureau of Labor Statistics (www.bls.gov) [cfch0008.pdf]
[f] Robert L. Vitra, "2008 Minerals Yearbook: Clay and Shale [Advance Release]" (U.S. Geological Survey, September 2010), http://minerals.usgs.gov/minerals/pubs/commodity/clays/myb1-2008-clays.pdf
[g] U.S. Life-Cycle Inventory Database, “Limestone, at mine,” http://www.nrel.gov/lci/database/default.asp (accessed 26 September 2010)
[h] Jim Mavis, “Water Use in Industries of the Future,” (U.S. Dept of Energy Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program, July 2003),
[i] U.S. Bureau of Labor Statistics, http://www.bls.gov/oes/current/naics4_327100.htm
[j] U.S. Bureau of Labor Statistics, May 2009 Occupational Employment and Wage Estimates: Metropolitan Area Cross-Industry Estimates, ftp://ftp.bls.gov/pub/special.requests/oes/oesm09ma.zip

TOTAL COST - EXTRACTION

	Units	2006	2008	Source
Quantity	metric tons	36,700,000	33,200,000	[f]
Value	dollars	$1,750,000,000	$1,640,000,000	[f]
Unit Value	per metric ton	$47.68	$49.40	calculation
Unit Value	per short ton	$43.26	$44.81	calculation

Conversions			
1 metric ton	=	1.1023113	short tons
1 kg	=	0.001	metric tons
1 kg	=	2.2046226	lbs

GHG EMISSIONS / CONVERSIONS

			Units	Source
1kg limestone	=	0.0000511	kg CO2-e	[g]
1 metric ton	=	0.0511	kg CO2-e	calculation
1 short ton	=	0.046357141	kg CO2-e	calculation
1 short ton	=	0.1022	lbs CO2-e	calculation

AVERAGE WAGES - EXTRACTION

SOC Code Number	Occupation	# (source [i])	% of Total Industry (Nonmetallic Mineral Mining and Quarrying, NAICS 212300) (source [i])	Mean Annual Wage (national) (source [i])	Weighted Mean Annual Wage (national) (calculated)	Mean Annual Wage (Cincinnati) (source [j])	Weighted Mean Annual Wage (Cincinnati) (calculated)	Median Annual Wage (Cincinnati) (source [j])	Weighted Median Annual Wage (Cincinnati) (calculated)
MANAGEMENT OCCUPATIONS									
11-1011	Chief Executives	210	0.21%	$176,130	$36,987,300	$172,730	$36,273,300	$172,730	$36,273,300
11-1021	General and Operations Mana	1,910	1.95%	$99,940	$190,885,400	$111,400	$212,774,000	$101,980	$194,781,800
11-2022	Sales Managers	140	0.14%	$99,650	$13,951,000	$114,620	$16,046,800	$101,390	$14,194,600
11-3031	Financial Managers	180	0.18%	$93,620	$16,851,600	$109,240	$19,663,200	$99,890	$17,980,200
11-3051	Industrial Production Manager	550	0.56%	$86,150	$47,382,500	$96,290	$52,959,500	$88,020	$48,411,000
11-3061	Purchasing Managers	40	0.04%	$80,390	$3,215,600	$91,560	$3,662,400	$87,490	$3,499,600
11-3071	Transportation, Storage, and I	50	0.05%	$96,810	$4,840,500	$81,940	$4,097,000	$77,560	$3,878,000
11-9021	Construction Managers	200	0.20%	$93,910	$18,782,000	$98,260	$19,652,000	$85,600	$17,120,000
11-9041	Engineering Managers	100	0.10%	$110,090	$11,009,000	$122,700	$12,270,000	$114,330	$11,433,000
11-9199	Managers, All Other	130	0.13%	$78,890	$10,255,700	$108,120	$14,055,600	$102,910	$13,378,300
BUSINESS AND FINANCIAL OCCUPATIONS									
13-1023	Purchasing Agents, Except Wh	250	0.26%	$51,300	$12,825,000	$56,340	$14,085,000	$53,680	$13,420,000
13-1041	Compliance Officers, Except A	70	0.07%	$55,430	$3,880,100	$54,970	$3,847,900	$50,410	$3,528,700
13-1051	Cost Estimators	90	0.09%	$53,560	$4,820,400	$63,440	$5,709,600	$59,780	$5,380,200
13-1073	Training and Development Spe	40	0.04%	$60,570	$2,422,800	$53,060	$2,122,400	$50,050	$2,002,000
13-1079	Human Resources, Training, a	60	0.06%	$53,040	$3,182,400	$52,440	$3,146,400	$49,580	$2,974,800
13-1199	Business Operations Specialist	80	0.08%	$54,280	$4,342,400	$61,170	$4,893,600	$57,050	$4,564,000
13-2011	Accountants and Auditors	410	0.42%	$68,290	$27,998,900	$63,950	$26,219,500	$57,530	$23,587,300
COMPUTER AND MATHEMATICAL SCIENCE OCCUPATIONS									
15-1041	Computer Support Specialists	30	0.03%	$48,140	$1,444,200	$44,780	$1,343,400	$42,240	$1,267,200
15-1071	Network and Computer Syster	40	0.04%	$62,930	$2,517,200	$64,650	$2,586,000	$63,940	$2,557,600
ARCHITECTURE AND ENGINEERING OCCUPATIONS									
17-1022	Surveyors	40	0.04%	$52,400	$2,096,000	$55,770	$2,230,800	$53,640	$2,145,600
17-2041	Chemical Engineers	30	0.03%	$92,910	$2,787,300	$89,800	$2,694,000	$81,210	$2,436,300
17-2051	Civil Engineers	40	0.04%	$66,580	$2,663,200	$76,940	$3,077,600	$74,130	$2,965,200
17-2081	Environmental Engineers	60	0.06%	$74,700	$4,482,000	$89,480	$5,368,800	$84,560	$5,073,600
17-2111	Health and Safety Engineers,	40	0.04%	$79,600	$3,184,000	$74,580	$2,983,200	$70,820	$2,832,800
17-2112	Industrial Engineers	210	0.21%	$71,350	$14,983,500	$76,380	$16,039,800	$73,660	$15,468,600
17-2141	Mechanical Engineers	40	0.04%	$72,770	$2,910,800	$76,120	$3,044,800	$69,850	$2,794,000
17-2151	Mining and Geological Enginee	310	0.32%	$72,040	$22,332,400	$78,510	$24,338,100	$76,070	$23,581,700
17-2199	Engineers, All Other	40	0.04%	$57,240	$2,289,600	$78,510	$3,140,400	$76,070	$3,042,800
17-3026	Industrial Engineering Technic	50	0.05%	$48,700	$2,435,000	$48,230	$2,411,500	$47,900	$2,395,000
LIFE, PHYSICAL SCIENCE, AND SOCIAL SCIENCE OCCUPATIONS									
19-4031	Chemical Technicians	570	0.58%	$45,460	$25,912,200	$42,330	$24,128,100	$41,000	$23,370,000
19-4099	Life, Physical, and Social Scier	40	0.04%	$42,270	$1,690,800	$42,990	$1,719,600	$39,430	$1,577,200
HEALTHCARE PRACTITIONER AND TECHNICAL OCCUPATIONS									
29-9011	Occupational Health and Safet	130	0.13%	$60,620	$7,880,600	$68,190	$8,864,700	$66,410	$8,633,300
PROTECTIVE SERVICE OCCUPATIONS									
33-9032	Security Guards	70	0.07%	$23,170	$1,621,900	$26,520	$1,856,400	$23,120	$1,618,400
BUILDING AND GROUNDS CLEANING AND MAINTENANCE OCCUPATIONS									
37-2011	Janitors and Cleaners, Except	190	0.19%	$26,310	$4,998,900	$24,140	$4,586,600	$22,260	$4,229,400
37-3011	Landscaping and Groundskeep	110	0.11%	$24,500	$2,695,000	$24,170	$2,658,700	$21,980	$2,417,800
SALES AND RELATED OCCUPATIONS									
41-2031	Retail Salespersons			$26,070		$24,700	$0	$19,640	$0

BRICK LCA APPENDIX A: DATA & SOURCES Extraction Data (continued)

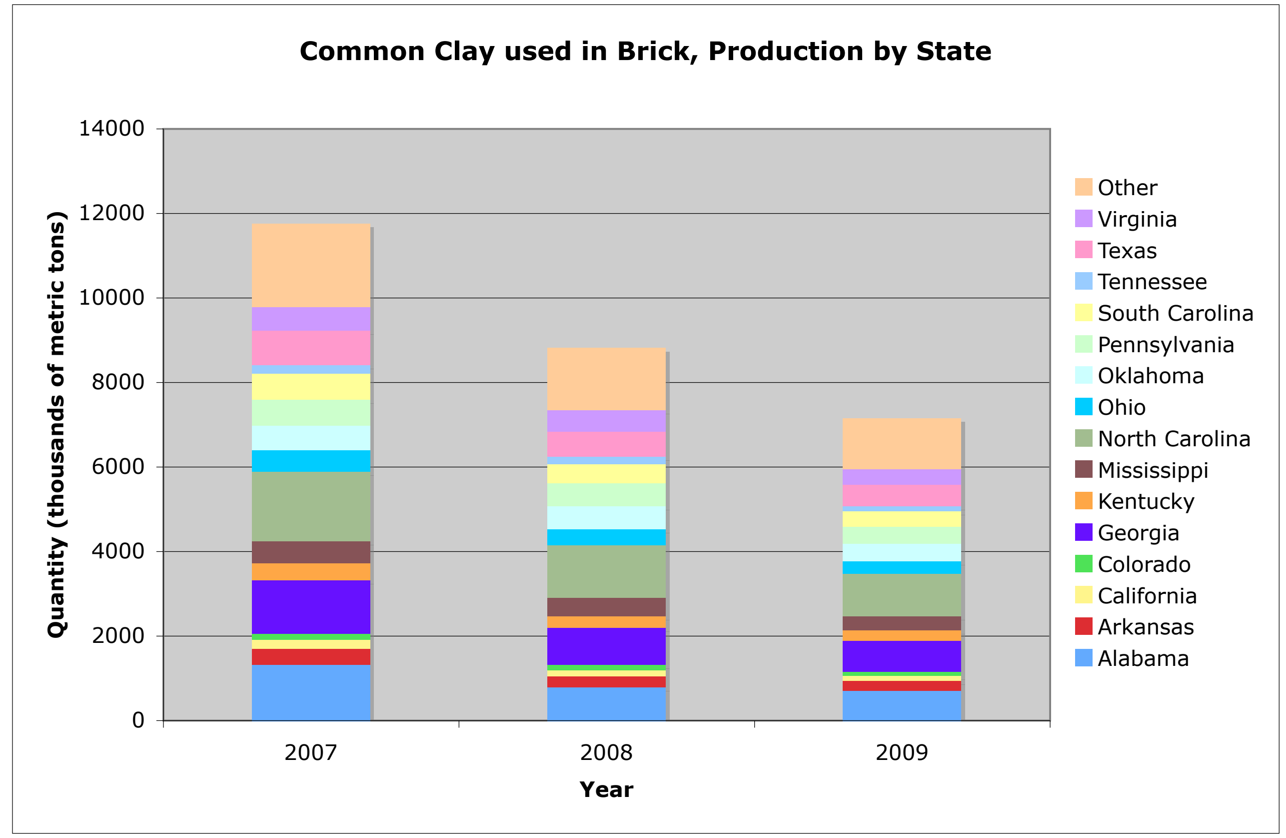
41-3099	Sales Representatives, Servic	100	0.10%	$63,880	$6,388,000	$54,080	$5,408,000	$46,060	$4,606,000
41-4012	Sales Representatives, Whole:	1,150	1.17%	$57,440	$66,056,000	$67,140	$77,211,000	$55,850	$64,227,500
OFFICE AND ADMINISTRATIVE SUPPORT OCCUPATIONS									
43-1011	First-Line Supervisors/Manage	610	0.62%	$48,290	$29,456,900	$48,990	$29,883,900	$46,050	$28,090,500
43-3021	Billing and Posting Clerks and	80	0.08%	$28,320	$2,265,600	$32,370	$2,589,600	$31,620	$2,529,600
43-3031	Bookkeeping, Accounting, and	1,390	1.42%	$33,810	$46,995,900	$34,730	$48,274,700	$33,810	$46,995,900
43-3051	Payroll and Timekeeping Clerk	190	0.19%	$35,120	$6,672,800	$36,360	$6,908,400	$36,040	$6,847,600
43-4051	Customer Service Representat	230	0.23%	$35,900	$8,257,000	$31,380	$7,217,400	$29,450	$6,773,500
43-4151	Order Clerks	50	0.05%	$28,260	$1,413,000	$31,220	$1,561,000	$30,080	$1,504,000
43-4161	Human Resources Assistants,	60	0.06%	$40,510	$2,430,600	$37,530	$2,251,800	$36,100	$2,166,000
43-4171	Receptionists and Information	190	0.19%	$25,530	$4,850,700	$23,820	$4,525,800	$23,320	$4,430,800
43-5032	Dispatchers, Except Police, Fir	660	0.67%	$37,430	$24,703,800	$38,260	$25,251,600	$35,830	$23,647,800
43-5061	Production, Planning, and Exp	100	0.10%	$45,040	$4,504,000	$40,700	$4,070,000	$38,540	$3,854,000
43-5071	Shipping, Receiving, and Traff	270	0.28%	$32,900	$8,883,000	$29,990	$8,097,300	$28,990	$7,827,300
43-5081	Stock Clerks and Order Fillers	140	0.14%	$35,180	$4,925,200	$24,250	$3,395,000	$21,330	$2,986,200
43-5111	Weighers, Measurers, Checker	1,260	1.29%	$29,990	$37,787,400	$28,220	$35,557,200	$27,580	$34,750,800
43-6011	Executive Secretaries and Adr	490	0.50%	$39,970	$19,585,300	$41,900	$20,531,000	$40,090	$19,644,100
43-6014	Secretaries, Except Legal, Me	1,070	1.09%	$28,400	$30,388,000	$31,670	$33,886,900	$30,820	$32,977,400
43-9061	Office Clerks, General	2,050	2.09%	$26,940	$55,227,000	$27,990	$57,379,500	$26,910	$55,165,500
CONSTRUCTION AND EXTRACION OCCUPATIONS									
47-1011	First-Line Supervisors/Manage	2,980	3.04%	$58,900	$175,522,000	$57,920	$172,601,600	$56,560	$168,548,800
47-2061	Construction Laborers	2,390	2.44%	$32,680	$78,105,200	$35,940	$85,896,600	$33,810	$80,805,900
47-2071	Paving, Surfacing, and Tampir	200	0.20%	$43,280	$8,656,000	$35,910	$7,182,000	$34,260	$6,852,000
47-2073	Operating Engineers and Othe	10,090	10.30%	$38,490	$388,364,100	$47,270	$476,954,300	$45,710	$461,213,900
47-2111	Electricians	910	0.93%	$53,240	$48,448,400	$46,070	$41,923,700	$48,210	$43,871,100
47-5021	Earth Drillers, Except Oil and	950	0.97%	$37,070	$35,216,500	$29,550	$28,072,500	$27,370	$26,001,500
47-5031	Explosives Workers, Ordnance	370	0.38%	$42,780	$15,828,600	$29,550	$10,933,500	$27,370	$10,126,900
47-5041	Continuous Mining Machine O	2,040	2.08%	$43,170	$88,066,800	$29,550	$60,282,000	$27,370	$55,834,800
47-5042	Mine Cutting and Channeling I	1,970	2.01%	$37,660	$74,190,200	$29,550	$58,213,500	$27,370	$53,918,900
47-5049	Mining Machine Operators, All	1,210	1.24%	$37,450	$45,314,500	$29,550	$35,755,500	$27,370	$33,117,700
47-5051	Rock Splitters, Quarry	2,650	2.71%	$29,670	$78,625,500	$29,550	$78,307,500	$27,370	$72,530,500
47-5061	Roof Bolters, Mining			$55,750		$29,550		$27,370	
47-5081	Helpers--Extraction Workers	1,250	1.28%	$29,990	$37,487,500	$29,550	$36,937,500	$27,370	$34,212,500
47-5099	Extraction Workers, All Other	950	0.97%	$36,200	$34,390,000	$29,550	$28,072,500	$27,370	$26,001,500
INSTALLATION, MAINTENANCE, AND REPAIR OCCUPATIONS									
49-1011	First-Line Supervisors/Manage	810	0.83%	$62,870	$50,924,700	$60,020	$48,616,200	$58,940	$47,741,400
49-3031	Bus and Truck Mechanics and	970	0.99%	$40,700	$39,479,000	$40,710	$39,488,700	$39,700	$38,509,000
49-3042	Mobile Heavy Equipment Mech	2,610	2.66%	$41,820	$109,150,200	$42,900	$111,969,000	$42,360	$110,559,600
49-9041	Industrial Machinery Mechanic	1,520	1.55%	$46,480	$70,649,600	$45,980	$69,889,600	$46,090	$70,056,800
49-9042	Maintenance and Repair Work	2,770	2.83%	$40,330	$111,714,100	$38,740	$107,309,800	$38,110	$105,564,700
49-9043	Maintenance Workers, Machin	870	0.89%	$36,500	$31,755,000	$37,910	$32,981,700	$36,430	$31,694,100
49-9044	Millwrights	490	0.50%	$49,940	$24,470,600	$49,980	$24,490,200	$48,650	$23,838,500
49-9069	Precision Instrument and Equi	40	0.04%	$49,700	$1,988,000	$50,850	$2,034,000	$50,900	$2,036,000
49-9098	Helpers--Installation, Mainten	380	0.39%	$33,220	$12,623,600	$23,970	$9,108,600	$22,550	$8,569,000
PRODUCTION OPERATIONS									
51-1011	First-Line Supervisors/Manage	1,390	1.42%	$56,530	$78,576,700	$56,680	$78,785,200	$55,430	$77,047,700
51-4035	Milling and Planing Machine S	90	0.09%	$36,000	$3,240,000	$36,810	$3,312,900	$36,870	$3,318,300
51-4041	Machinists	200	0.20%	$48,350	$9,670,000	$38,700	$7,740,000	$37,130	$7,426,000
51-4121	Welders, Cutters, Solderers, a	900	0.92%	$37,410	$33,669,000	$36,770	$33,093,000	$36,550	$32,895,000
51-8021	Stationary Engineers and Boil	60	0.06%	$55,910	$3,354,600	$51,390	$3,083,400	$51,410	$3,084,600
51-8099	Plant and System Operators, /	480	0.49%	$43,090	$20,683,200	$61,660	$29,596,800	$65,180	$31,286,400
51-9012	Separating, Filtering, Clarifyin	760	0.78%	$37,190	$28,264,400	$38,420	$29,199,200	$38,820	$29,503,200
51-9021	Crushing, Grinding, and Polish	3,540	3.61%	$34,990	$123,864,600	$30,100	$106,554,000	$29,570	$104,677,800
51-9023	Mixing and Blending Machine	490	0.50%	$37,290	$18,272,100	$40,390	$19,791,100	$41,380	$20,276,200
51-9032	Cutting and Slicing Machine S	540	0.55%	$30,370	$16,399,800	$32,210	$17,393,400	$32,480	$17,539,200
51-9051	Furnace, Kiln, Oven, Drier, an	450	0.46%	$38,870	$17,491,500	$31,310	$14,089,500	$30,650	$13,792,500
51-9061	Inspectors, Testers, Sorters, S	1,150	1.17%	$35,510	$40,836,500	$35,520	$40,848,000	$34,290	$39,433,500
51-9111	Packaging and Filling Machine	1,120	1.14%	$32,800	$36,736,000	$31,390	$35,156,800	$29,550	$33,096,000

51-9195	Molders, Shapers, and Casters			$35,670		$27,010		$24,910	
51-9198	Helpers--Production Workers	980	1.00%	$27,640	$27,087,200	$26,030	$25,509,400	$24,710	$24,215,800
51-9199	Production Workers, All Other	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/Manage	410	0.42%	$48,310	$19,807,100	$47,200	$19,352,000	$44,890	$18,404,900
53-1031	First-Line Supervisors/Manage	1,200	1.23%	$54,820	$65,784,000	$53,570	$64,284,000	$51,230	$61,476,000
53-3032	Truck Drivers, Heavy and Trac	9,600	9.80%	$35,310	$338,976,000	$39,480	$379,008,000	$37,480	$359,808,000
53-3033	Truck Drivers, Light or Deliver	440	0.45%	$31,690	$13,943,600	$31,970	$14,066,800	$28,610	$12,588,400
53-4013	Rail Yard Engineers, Dinkey O	50	0.05%	$39,870	$1,993,500	$39,870	$1,993,500	$39,870	$1,993,500
53-7011	Conveyor Operators and Tend	950	0.97%	$36,260	$34,447,000	$31,980	$30,381,000	$33,690	$32,005,500
53-7021	Crane and Tower Operators	200	0.20%	$39,010	$7,802,000	$38,710	$7,742,000	$36,360	$7,272,000
53-7031	Dredge Operators	1,030	1.05%	$35,040	$36,091,200	$40,760	$41,982,800	$37,800	$38,934,000
53-7032	Excavating and Loading Machi	7,390	7.55%	$34,410	$254,289,900	$40,760	$301,216,400	$37,800	$279,342,000
53-7033	Loading Machine Operators, U	700	0.71%	$37,330	$26,131,000	$40,760	$28,532,000	$37,800	$26,460,000
53-7041	Hoist and Winch Operators	30	0.03%	$44,060	$1,321,800	$44,060	$1,321,800	$44,060	$1,321,800
53-7051	Industrial Truck and Tractor O	2,150	2.20%	$32,890	$70,713,500	$30,560	$65,704,000	$30,230	$64,994,500
53-7061	Cleaners of Vehicles and Equi	50	0.05%	$31,510	$1,575,500	$23,290	$1,164,500	$21,210	$1,060,500
53-7062	Laborers and Freight, Stock, a	3,660	3.74%	$27,140	$99,332,400	$25,190	$92,195,400	$23,400	$85,644,000
53-7063	Machine Feeders and Offbeare	310	0.32%	$27,610	$8,559,100	$29,480	$9,138,800	$26,130	$8,100,300
53-7064	Packers and Packagers, Hand	90	0.09%	$23,920	$2,152,800	$21,600	$1,944,000	$20,450	$1,840,500
53-7072	Pump Operators, Except Wellh	110	0.11%	$33,240	$3,656,400	$33,240	$3,656,400	$33,240	$3,656,400
53-7111	Shuttle Car Operators	100	0.10%	$49,970	$4,997,000	$39,780	$3,978,000	$37,790	$3,779,000
53-7121	Tank Car, Truck, and Ship Loa	140	0.14%	$41,520	$5,812,800	$39,780	$5,569,200	$37,790	$5,290,600
53-7199	Material Moving Workers, All C	70	0.07%	$30,730	$2,151,100	$39,780	$2,784,600	$37,790	$2,645,300
		96350	98.28%		$3,921,081,600		$4,039,208,000		$3,851,819,300
		98.38%			$40,696		$41,922.24		$39,977.37

Brick Production: Top Clay-Mining States

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

State	Quantity (thousand metric tons) 2007	%	Quantity (thousand metric tons) 2008	%	Quantity (thousand metric tons) 2009	%
Alabama	1320	11.22%	782	8.86%	718	10.04%
Arkansas	380	3.23%	257	2.91%	220	3.07%
California	211	1.79%	164	1.86%	131	1.83%
Colorado	154	1.31%	108	1.22%	91	1.27%
Georgia	1260	10.71%	884	10.02%	741	10.37%
Kentucky	409	3.48%	275	3.12%	236	3.30%
Mississippi	508	4.32%	433	4.91%	330	4.61%
North Carolina	1650	14.03%	1250	14.17%	1008	14.10%
Ohio	495	4.21%	379	4.30%	304	4.25%
Oklahoma	601	5.11%	541	6.13%	402	5.62%
Pennsylvania	603	5.13%	555	6.29%	408	5.71%
South Carolina	619	5.26%	453	5.13%	372	5.20%
Tennessee	199	1.69%	155	1.76%	123	1.72%
Texas	814	6.92%	604	6.85%	492	6.88%
Virginia	561	4.77%	502	5.69%	374	5.23%
Other	1980	16.83%	1480	16.78%	1201	16.80%
TOTAL	11764		8822		7150	
% for Brick	57.11%		57.29%		57.20%	
Total Common Clay	20,600		15,400		12,500	
Top 4 Total:			3520	39.90%		



Manufacturing of Standard Bricks

Economic & environmental data from three US Dept. of Energy ITP Assessments. Ethical data from the US Bureau of Labor Statistics, as follows: wage data based upon "Clay Product & Refractory Manufacturing," NAICS code 327100; fatality data based upon the "Manufacturing" sector (see reference [e] below); injury/illness data based upon "Brick and structural clay tile manufacturing," NAICS code 327121.

		Assessment #UA0022		Assessment #NC0352		Assessment #CO0578		Average / Overall Industry	
Metric	Units	Quantity	Source	Quantity	Source	Quantity	Source	Quantity	Source
ECONOMIC									
Material cost	$ / ton								
Labor cost	$ / ton								
Total cost	$ / ton								
Total sales	dollars	$17,000,000	[d]	$8,000,000	[d]	$22,000,000	[d]		
Total output	bricks	118,000,000	[d]	160,000,000	[d]	42,000,000	[d]		
Total output	tons	267,344	calc.	362,500	calc.	95,156	calc.		
Revenue per unit	$ / brick	$0.14	calc.	$0.05	calc.	$0.52	calc.	$0.24	calculated
Revenue per ton	$ / ton	$63.59	calc.	$22.07	calc.	$231.20	calc.	$105.62	calculated
ENVIRONMENTAL									
Emissions to air									
GHG emissions	lbs CO2e / ton							786.07	calculated
GHG emissions from electricity	lbs CO2e / ton							633.53	calculated
GHG emissions from nat. gas	lbs CO2e / ton							152.54	calculated
Energy use	MMBtu	454,973	[d]	575,030	[d]	162,902	[d]		
Electricity	kWh	9,164,168	[d]	11,078,300	[d]	3,931,200	[d]		
Electricity % of total	%	20.65%	calc.	19.75%	calc.	24.74%	calc.	22%	calculated
Natural Gas	MMBtu	361,040	[d]	461,477	[d]	122,607	[d]		
Nat. Gas % of total	%	79.35%	calc.	80.25%	calc.	75.26%	calc.	78%	calculated
Energy use per ton	MMBtu / ton							1.67	calculated
Electricity	MMBtu / ton							0.12	calculated
Natural Gas	MMBtu / ton							1.30	calculated
Energy use per unit	Btu / brick	3855.70	calc.	3593.94	calc.	3878.62	calc.	3,776.09	calculated
Electricity	kWh / brick	0.0777	calc.	0.0692	calc.	0.0936	calc.	0.08	calculated
Natural Gas	Btu / brick	3059.66	calc.	2884.23	calc.	2919.21	calc.	2,954.37	calculated
Water use	gal / ton								
ETHICAL									
Injury / illness rate	cases per 100 employees							7.0	[a]
relative to all occupations	%							189.2%	[a]
Fatality rate	per 100,000 / yr							2.2	[e]
relative to all occupations	%							66.7%	[e]
Annual wage (Cincinnati)									
Mean	$ / yr							$31,677	calculated
Median	$ / yr							$31,483	calculated
% of local avg. wage									
Mean	%							75%	calculated
Median	%							96%	calculated

Sources

[a] U.S. Bureau of Labor Statistics, "Incidence rates of nonfatal occupational injuries and illnesses by industry and case types, 2008" (http://www.bls.gov/iif/oshwc/osh/os/ostb2071.pdf)
[b] National Mining Association (NMA), "Mining in North Carolina, 2004" (http://www.nma.org/pdf/states/nc2004.pdf)
[c] National Mining Association (NMA), "Mining in North Carolina, 2007" (http://www.nma.org/pdf/states/econ/nc.pdf)
[d] U.S. Dept of Energy, Energy Efficiency and Renewable Energy, Industrial Technologies Program, "IAC Assessment Statistics" (2010)
(http://iac.rutgers.edu/database/statistics/?STATE=&CENTER=&YEAR_limit=%3C%3D&YEAR=2010&SIC=&NAICS=327121&search=Search)
[e] U.S. Bureau of Labor Statistics (www.bls.gov) [cfch0008.pdf]
[f] Robert L. Vitra, "2008 Minerals Yearbook: Clay and Shale [Advance Release]" (U.S. Geological Survey, September 2010),
http://minerals.usgs.gov/minerals/pubs/commodity/clays/myb1-2008-clays.pdf
[g] U.S. Life-Cycle Inventory Database, "Limestone, at mine," http://www.nrel.gov/lci/database/default.asp (accessed 26 September 2010)
[h] Jim Mavis, "Water Use in Industries of the Future," (U.S. Dept of Energy Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program, July 2003),
http://www1.eere.energy.gov/industry/mining/pdfs/water_use_mining.pdf
[i] U.S. Energy Information Administration, http://www.eia.doe.gov/oiaf/1605/coefficients.html
[j] U.S. EPA, http://cfpub.epa.gov/egridweb/ghg.cfm
[m] U.S. Bureau of Labor Statistics, http://www.bls.gov/oes/current/naics4_327100.htm
[n] U.S. Bureau of Labor Statistics, May 2009 Occupational Employment and Wage Estimates: Metropolitan Area Cross-Industry Estimates,
ftp://ftp.bls.gov/pub/special.requests/oes/oesm09ma.zip

EMISSION FACTORS			Units	Source
1 MMBTU natural gas	=	53.06	kgCO2	[i]
1 MWh electricity in Ohio	=	1,538	lbsCO2	[j]
1 MWh	=	3412141.63	BTU	[k]
1 MMBTU	=	1,000,000	BTU	given
1 MMBTU electricity in Ohio	=	5247.26	lbsCO2	calculated
1 kg	=	2.2046226	lbs	given

AVERAGE WAGES - MANUFACTURING

Production Occupation	SOC Code Number	% of Total Industry (Clay Product & Refractory Manufacturing, NAICS 327100)	#	Mean Annual Wage (national)	Source	Weighted Mean Annual Wage (national)	Mean Annual Wage (Cincinnati)	Weighted Mean Annual Wage (Cincinnati)	Median Annual Wage (national)	Weighted Median Annual Wage (national)	Median Annual Wage (Cincinnati)	Source	Weighted Median Annual Wage (Cincinnati)
Molders, Shapers, and Casters, Except Metal and Plastic	51-9195	7.03%	3160	$28,830	[m]	$91,102,800	$27,010	$85,351,600	$28,160	$88,985,600	$24,910	[n]	$78,715,600
Extruding, Forming, Pressing, and Compacting Machine Setters, Operators, and Tenders	51-9041	5.52%	2480	$29,710	[m]	$73,680,800	$33,470	$83,005,600	$28,990	$71,895,200	$27,590	[n]	$68,423,200
Furnace, Kiln, Oven, Drier, and Kettle Operators and Tenders	51-9051	4.76%	2140	$31,120	[m]	$66,596,800	$31,310	$67,003,400	$29,700	$63,558,000	$33,370	[n]	$71,411,800
First-Line Supervisors/Managers of Production and Operating Workers	51-1011	4.63%	2080	$52,060	[m]	$108,284,800	$35,080	$72,966,400	$50,030	$104,062,400	$53,690	[n]	$111,675,200
Inspectors, Testers, Sorters, Samplers, and Weighers	51-9061	3.98%	1790	$33,280	[m]	$59,571,200	$35,520	$63,580,800	$31,390	$56,188,100	$32,680	[n]	$58,497,200
Helpers--Production Workers	51-9198	3.65%	1640	$25,190	[m]	$41,311,600	$26,030	$42,689,200	$24,010	$39,376,400	$21,550	[n]	$35,342,000
Team Assemblers	51-2092	3.38%	1520	$26,310	[m]	$39,991,200	$29,610	$45,007,200	$26,000	$39,520,000	$26,680	[n]	$40,553,600
Mixing and Blending Machine Setters, Operators, and Tenders	51-9023	3.38%	1520	$31,400	[m]	$47,728,000	$40,390	$61,392,800	$30,980	$47,089,600	$32,970	[n]	$50,114,400
Machinists	51-4041	2.09%	940	$35,150	[m]	$33,041,000	$38,700	$36,378,000	$34,050	$32,007,000	$36,790	[n]	$34,582,600
Painting, Coating, and Decorating Workers	51-9123	2.07%	930	$24,350	[m]	$22,645,500	$22,270	$20,711,100	$22,770	$21,176,100	$24,900	[n]	$23,157,000
Coating, Painting, and Spraying Machine Setters, Operators, and Tenders	51-9121	2.00%	900	$27,570	[m]	$24,813,000	$34,270	$30,843,000	$26,960	$24,264,000	$28,640	[n]	$25,776,000
Crushing, Grinding, and Polishing Machine Setters, Operators, and Tenders	51-9021	1.98%	890	$31,530	[m]	$28,061,700	$30,100	$26,789,000	$30,110	$26,797,900	$38,490	[n]	$34,256,100
Production Workers, All Other	51-9199	1.42%	640	$26,570	[m]	$17,004,800	$29,280	$18,739,200	$26,060	$16,678,400	$36,120	[n]	$23,116,800
Cutting and Slicing Machine Setters, Operators, and Tenders	51-9032	1.00%	450	$29,600	[m]	$13,320,000	$32,210	$14,494,500	$28,970	$13,036,500	$29,480	[n]	$13,266,000
Packaging and Filling Machine Operators and Tenders	51-9111	0.87%	390	$29,000	[m]	$11,310,000	$31,390	$12,242,100	$28,620	$11,161,800	$23,440	[n]	$9,141,600
Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic	51-4031	0.87%	390	$30,300	[m]	$11,817,000	$31,510	$12,288,900	$30,150	$11,758,500	$28,890	[n]	$11,267,100
Grinding and Polishing Workers, Hand	51-9022	0.82%	370	$27,900	[m]	$10,323,000	$28,930	$10,704,100	$26,710	$9,882,700	$28,590	[n]	$10,578,300
			22230			$700,603,200		$704,186,900		$677,438,200			$699,874,500
		90.11%				$31,516		$31,677		$30,474			$31,483.33

OVERALL WAGE FIGURES		Source
Mean Annual Wage, All Occupations, Cincinnati	$42,340	[n]
Median Annual Wage, All Occupations, Cincinnati	$32,950	[n]

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)							
		Extraction to manufacture		**Manufacture to assembly**		**Assembly to disposal**		**TOTAL**	
	Units	Q	Source	Q	Source	Q	Source	Q	Source
TRANSPORT INFO									
Distance traveled	miles	0	[3]	123	[2]	10.6	[2]	133.6	calc.
Type of transport	N/A	N/A		road	[3]	road	est.	road	
ECONOMIC									
Per unit cost	$ / ton-mile	$0.251	[1]	$0.251	[1]	$0.251	[1]		
Total cost - source 1	$ / ton	$0.00		$30.87	calc.	$2.66	calc.	$33.53	calc.
Total cost - source 2	$ / ton	N/A		$62.50	[8]	N/A		$65.16	[8]
ENVIRONMENTAL									
Emissions to air									
GHG emissions	lbs CO2-e / full truck load	0	[6,7]	455.1	[6,7]	39.22	[6,7]	494.32	
GHG emissions	lbs CO2-e / ton	0	[14]	34.87	[14]	3.01	[14]	37.88	
Energy use	MMBTU / ton	NO DATA		NO DATA		NO DATA		NO DATA	
Water use	gal / ton	NO DATA		NO DATA		NO DATA		NO DATA	
ETHICAL									
Injury / illness rate	cases per 100 employees							NO DATA	
relative to all occupations	%							NO DATA	
Fatalities	per 100,000 employees							NO DATA	
relative to all occupations	%							NO DATA	
Annual wage (Cincinnati)									
Mean	$ / yr							$39,180	[10]
Median	$ / yr							$37,770	[10]
% local avg. wage									
Mean	%							97.2%	calc.
Median	%							118.7%	calc.

	General Industry Data (Brick in the U.S.)							
	Extraction to manufacture		**Manufacture to assembly**		**Assembly to disposal**		**TOTAL**	
	Q	Source	Q	Source	Q	Source	Q	Source
TRANSPORT INFO								
Distance traveled	15	[4]	200	[5]	50	est.	265	calc.
Type of transport	road	[4]	road	[4]	road	est.	road	
ECONOMIC								
Per unit cost	$0.251	[1]	$0.251	[1]	$0.251	[1]		
Total cost - source 1	$3.77	calc.	$50.20	calc.	$12.55	calc.	$66.52	calc.
Total cost - source 2	N/A		N/A		N/A			N/A
ENVIRONMENTAL								
Emissions to air								
GHG emissions	55.5	[6,7]	740	[6,7]	185	[6,7]	980.5	calc.
GHG emissions	4.25	[14]	56.70	[14]	14.18	[14]	75.13	calc.
Energy use	NO DATA		NO DATA		NO DATA		NO DATA	
Water use	NO DATA		NO DATA		NO DATA		NO DATA	
ETHICAL								
Injury / illness rate							5.5	[11]
relative to all occupations							148.6%	[11]
Fatalities							18.3	[12]
relative to all occupations							554.5%	[12]
Annual wage (Cincinnati)								
Mean							$39,260	[9]
Median							$37,730	[9]
% local avg. wage								
Mean							92.7%	calc.
Median							114.5%	calc.

Sources

[1] http://people.hofstra.edu/geotrans/eng/ch3en/conc3en/modaltransportcosttonmile.html
[2] Google Maps (www.google.com/maps)
[3] http://www.hansonbrick.com/en/builder/green_leed.php
[4] Brick Institute of America, as cited in "Building With Brick," Boral Bricks, Inc., December 2009, http://boralbricks.com/images/Users/1/PastelCote/News/WhitePaperSustainable_BoralLetterhead.pdf
[5] Brick Industry Association, "Sustainability and Brick," June 2009, http://www.gobrick.com/BIA/technotes/TN48.pdf
[6] U.S. EPA, http://www.epa.gov/otaq/climate/420f05003.htm
[7] Lawrence Livermore National Laboratory, https://www.llnl.gov/news/newsreleases/2010/NR-10-02-08.html
[8] U Ship Price Estimator, http://www.uship.com/price_estimator.aspx?v=0&z1=40380&z2=45220&w=12000&c=417&s=150
[9] U.S. Bureau of Labor Statistics, http://www.bls.gov/oes/current/oes533032.htm
[10] U.S. Bureau of Labor Statistics, http://data.bls.gov:8080/oes/datatype.do
[11] U.S. Bureau of Labor Statistics, "Incidence rates of nonfatal occupational injuries and illnesses by industry and case types, 2008" (http://www.bls.gov/iif/oshwc/osh/os/ostb2071.pdf)
[12] U.S. Bureau of Labor Statistics, "Census of Fatal Occupational Injuries Charts, 1992-2009," http://www.bls.gov/iif/oshwc/cfoi/cfch0008.pdf
[13] U.S. EPA, http://www.epa.gov/otaq/toxics.htm
[14] http://www.pioneersand.com/wholesale/flagstone/flagstone.htm

Transit type	Cost	Units	Source
Water	0.007	$/ton-mi	[1]
Rail	0.025	$/ton-mi	[1]
Road	0.251	$/ton-mi	[1]
Air	0.588	$/ton-mi	[1]

Environmental Impacts - Diesel Fuel

Diesel	22.2	lbs CO2	[6]
Gasoline	19.4	lbs CO2	[6]
Semi truck efficienc	6	mpg	[7]
CO2 per mile	3.7	lbs CO2 per mile	

Conversions

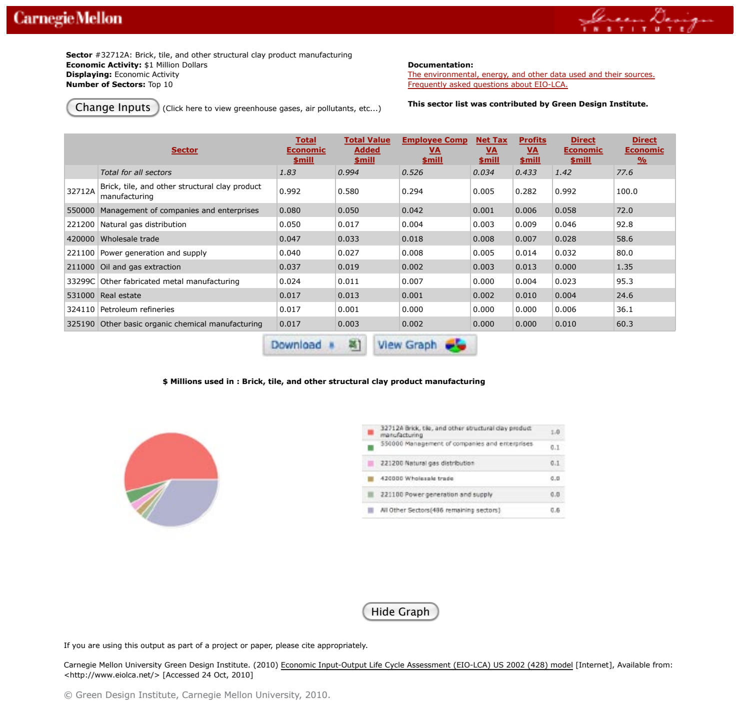
1 semi	=	12	pallets brick
1 pallet brick	=	480	bricks
1 brick	=	4.5313	lbs
1 pallet bricks	=	2175	lbs
1 pallet brick	=	1.0875	tons
1 semi	=	13.05	tons

Composition of a Brick Wall

Component	%	Source	Quantity	Units	Source
Composition of Brick Wall					
By Volume					
Standard brick	71.07%	[d]	0.2677	c.f. brick	[d]
Mortar (type N)	28.93%	[d]	0.1090	c.f. mortar	[d]
By Weight					
Standard brick	68.59%	[e]	0.0161	tons / s.f. wall	[e]
Mortar (type N)	31.41%	[e]	0.0074	tons / s.f. wall	[e]
Composition of Brick			per ton		
By Material Used in Production					
Clay & bottom ash	85%	[a]	1700	lbs / ton	calc.
Water	15%	[b]	300	lbs / ton	calc.
Manganese	negligible	[a, b]	0	lbs / ton	calc.
By Mass					
Clay	99.2%	[f]	1984	lbs / ton	calc.
Bottom ash	0.08%	[f]	1.6	lbs / ton	calc.
Composition of Type N Mortar by Volume					
Portland cement	9.4%	calc.	3.375	c.f.	[c]
Hydrated lime	9.4%	calc.	3.375	c.f.	[c]
Sand	56.3%	calc.	20.25	c.f.	[c]
Water	25.0%	[f]	9.00	c.f.	calc.
TOTAL	100.0%	calc.	36.00	c.f.	calc.
Composition of Portland Cement					
Limestone	71.7%	calc.	1.17	kg	[g]
Cement rock / marl	12.9%	calc.	0.21	kg	[g]
Clay	3.7%	calc.	0.06	kg	[g]
Shale	3.1%	calc.	0.05	kg	[g]
Sand	2.5%	calc.	0.04	kg	[g]
Slag	1.2%	calc.	0.02	kg	[g]
Iron / iron ore	0.6%	calc.	0.01	kg	[g]
Fly ash	0.6%	calc.	0.01	kg	[g]
Bottom ash	0.6%	calc.	0.01	kg	[g]
Foundry sand	0.2%	calc.	0.004	kg	[g]
Slate	0.1%	calc.	0.001	kg	[g]
Gypsum	2.9%	calc.	0.048	kg	[g]
TOTAL	100.0%	calc.	1.633	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%	calc.			

Sources

[a] http://www.mc2-ice.com/support/estref/popular_conversion_files/masonry/mortar.htm
[b] http://www.umich.edu/~bricks/brickwebsite/setting_drying/setting_drying_page3.htm
[c] http://www.mc2-ice.com/support/estref/popular_conversion_files/masonry/mortar.htm
[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. Hafner & Sons, http://www.hafners.com. Further research is needed to determine in this rate is typical.



Carnegie Mellon

Sector #32712A: Brick, tile, and other structural clay product manufacturing
Economic Activity: $1 Million Dollars
Displaying: Economic Activity
Number of Sectors: Top 10

Documentation:
The environmental, energy, and other data used and their sources.
Frequently asked questions about EIO-LCA.

Change Inputs (Click here to view greenhouse gases, air pollutants, etc...)

This sector list was contributed by Green Design Institute.

	Sector	Total Economic $mill	Total Value Added $mill	Employee Comp VA $mill	Net Tax VA $mill	Profits VA $mill	Direct Economic $mill	Direct Economic %
	Total for all sectors	*1.83*	*0.994*	*0.526*	*0.034*	*0.433*	*1.42*	*77.6*
32712A	Brick, tile, and other structural clay product manufacturing	0.992	0.580	0.294	0.005	0.282	0.992	100.0
550000	Management of companies and enterprises	0.080	0.050	0.042	0.001	0.006	0.058	72.0
221200	Natural gas distribution	0.050	0.017	0.004	0.003	0.009	0.046	92.8
420000	Wholesale trade	0.047	0.033	0.018	0.008	0.007	0.028	58.6
221100	Power generation and supply	0.040	0.027	0.008	0.005	0.014	0.032	80.0
211000	Oil and gas extraction	0.037	0.019	0.002	0.003	0.013	0.000	1.35
33299C	Other fabricated metal manufacturing	0.024	0.011	0.007	0.000	0.004	0.023	95.3
531000	Real estate	0.017	0.013	0.001	0.002	0.010	0.004	24.6
324110	Petroleum refineries	0.017	0.001	0.000	0.000	0.000	0.006	36.1
325190	Other basic organic chemical manufacturing	0.017	0.003	0.002	0.000	0.000	0.010	60.3

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$ Millions used in : Brick, tile, and other structural clay product manufacturing

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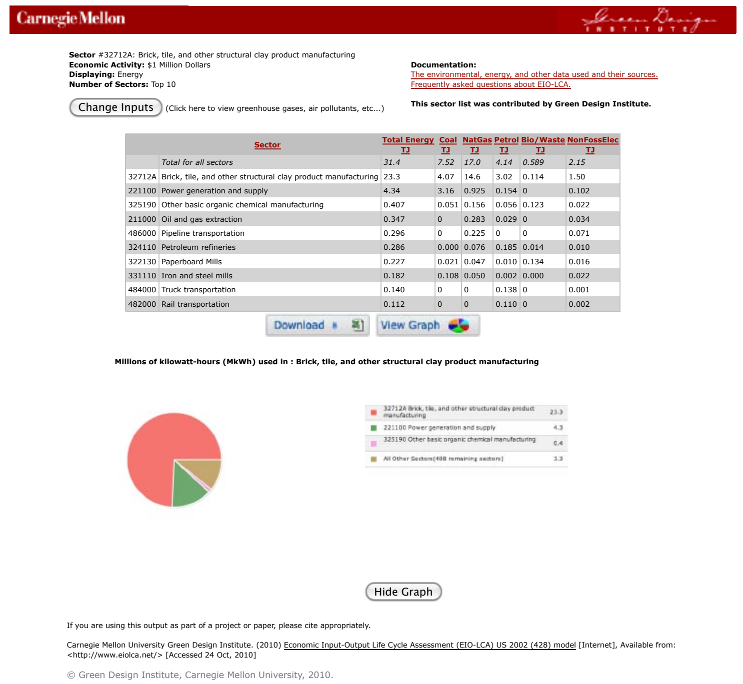

Carnegie Mellon

Sector #32712A: Brick, tile, and other structural clay product manufacturing
Economic Activity: $1 Million Dollars
Displaying: Energy
Number of Sectors: Top 10

Documentation:
The environmental, energy, and other data used and their sources.
Frequently asked questions about EIO-LCA.

Change Inputs (Click here to view greenhouse gases, air pollutants, etc...)

This sector list was contributed by Green Design Institute.

	Sector	Total Energy TJ	Coal TJ	NatGas TJ	Petrol TJ	Bio/Waste TJ	NonFossElec TJ
	Total for all sectors	*31.4*	*7.52*	*17.0*	*4.14*	*0.589*	*2.15*
32712A	Brick, tile, and other structural clay product manufacturing	23.3	4.07	14.6	3.02	0.114	1.50
221100	Power generation and supply	4.34	3.16	0.925	0.154	0	0.102
325190	Other basic organic chemical manufacturing	0.407	0.051	0.156	0.056	0.123	0.022
211000	Oil and gas extraction	0.347	0	0.283	0.029	0	0.034
486000	Pipeline transportation	0.296	0	0.225	0	0	0.071
324110	Petroleum refineries	0.286	0.000	0.076	0.185	0.014	0.010
322130	Paperboard Mills	0.227	0.021	0.047	0.010	0.134	0.016
331110	Iron and steel mills	0.182	0.108	0.050	0.002	0.000	0.022
484000	Truck transportation	0.140	0	0	0.138	0	0.001
482000	Rail transportation	0.112	0	0	0.110	0	0.002

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Millions of kilowatt-hours (MkWh) used in : Brick, tile, and other structural clay product manufacturing

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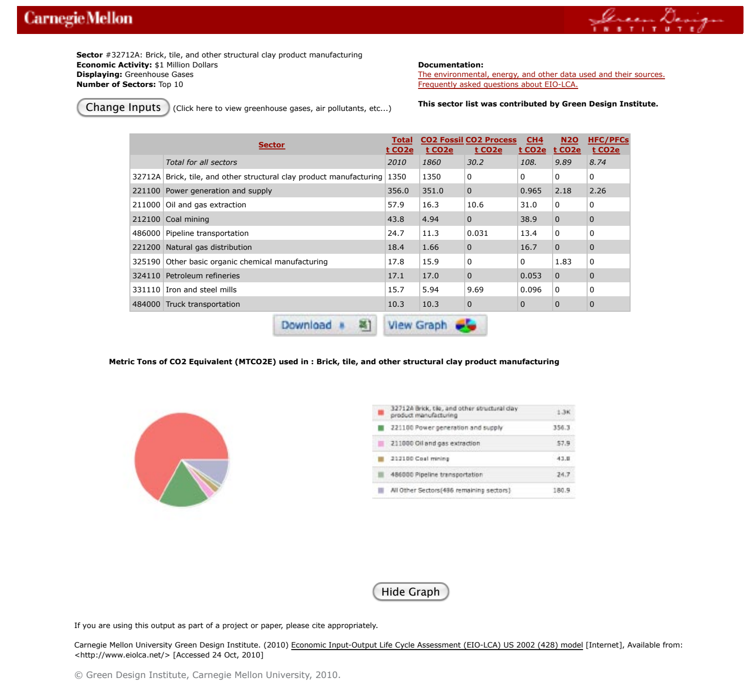

Carnegie Mellon

Sector #32712A: Brick, tile, and other structural clay product manufacturing
Economic Activity: $1 Million Dollars
Displaying: Greenhouse Gases
Number of Sectors: Top 10

Documentation:
The environmental, energy, and other data used and their sources.
Frequently asked questions about EIO-LCA.

Change Inputs (Click here to view greenhouse gases, air pollutants, etc...)

This sector list was contributed by Green Design Institute.

	Sector	Total t CO2e	CO2 Fossil t CO2e	CO2 Process t CO2e	CH4 t CO2e	N2O t CO2e	HFC/PFCs t CO2e
	Total for all sectors	*2010*	*1860*	*30.2*	*108.*	*9.89*	*8.74*
32712A	Brick, tile, and other structural clay product manufacturing	1350	1350	0	0	0	0
221100	Power generation and supply	356.0	351.0	0	0.965	2.18	2.26
211000	Oil and gas extraction	57.9	16.3	10.6	31.0	0	0
212100	Coal mining	43.8	4.94	0	38.9	0	0
486000	Pipeline transportation	24.7	11.3	0.031	13.4	0	0
221200	Natural gas distribution	18.4	1.66	0	16.7	0	0
325190	Other basic organic chemical manufacturing	17.8	15.9	0	0	1.83	0
324110	Petroleum refineries	17.1	17.0	0	0.053	0	0
331110	Iron and steel mills	15.7	5.94	9.69	0.096	0	0
484000	Truck transportation	10.3	10.3	0	0	0	0

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Metric Tons of CO2 Equivalent (MTCO2E) used in : Brick, tile, and other structural clay product manufacturing

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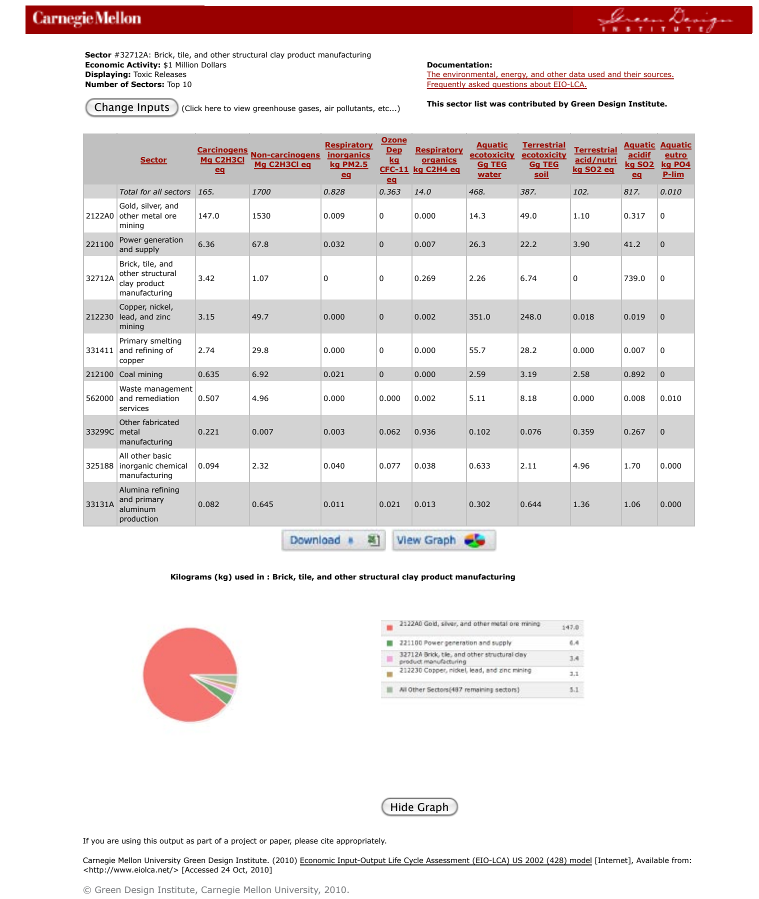

Carnegie Mellon

Sector #32712A: Brick, tile, and other structural clay product manufacturing
Economic Activity: $1 Million Dollars
Displaying: Toxic Releases
Number of Sectors: Top 10

Documentation:
The environmental, energy, and other data used and their sources.
Frequently asked questions about EIO-LCA.

Change Inputs (Click here to view greenhouse gases, air pollutants, etc...)

This sector list was contributed by Green Design Institute.

	Sector	Carcinogens Mg C2H3Cl eq	Non-carcinogens Mg C2H3Cl eq	Respiratory inorganics kg PM2.5 eq	Ozone Dep kg CFC-11 eq	Respiratory organics kg C2H4 eq	Aquatic ecotoxicity Gg TEG water	Terrestrial ecotoxicity Gg TEG soil	Terrestrial acid/nutri kg SO2 eq	Aquatic acidif kg SO2 eq	Aquatic eutro kg PO4 P-lim
	Total for all sectors	*165.*	*1700*	*0.828*	*0.363*	*14.0*	*468.*	*387.*	*102.*	*817.*	*0.010*
2122A0	Gold, silver, and other metal ore mining	147.0	1530	0.009	0	0.000	14.3	49.0	1.10	0.317	0
221100	Power generation and supply	6.36	67.8	0.032	0	0.007	26.3	22.2	3.90	41.2	0
32712A	Brick, tile, and other structural clay product manufacturing	3.42	1.07	0	0	0.269	2.26	6.74	0	739.0	0
212230	Copper, nickel, lead, and zinc mining	3.15	49.7	0.000	0	0.002	351.0	248.0	0.018	0.019	0
331411	Primary smelting and refining of copper	2.74	29.8	0.000	0	0.000	55.7	28.2	0.000	0.007	0
212100	Coal mining	0.635	6.92	0.021	0	0.000	2.59	3.19	2.58	0.892	0
562000	Waste management and remediation services	0.507	4.96	0.000	0.000	0.002	5.11	8.18	0.000	0.008	0.010
33299C	Other fabricated metal manufacturing	0.221	0.007	0.003	0.062	0.936	0.102	0.076	0.359	0.267	0
325188	All other basic inorganic chemical manufacturing	0.094	2.32	0.040	0.077	0.038	0.633	2.11	4.96	1.70	0.000
33131A	Alumina refining and primary aluminum production	0.082	0.645	0.011	0.021	0.013	0.302	0.644	1.36	1.06	0.000

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Kilograms (kg) used in : Brick, tile, and other structural clay product manufacturing

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Comparison to EIOLCA: Economic Activity & GHG Emissions

	ECONOMIC ACTIVITY						GREENHOUSE GAS EMISSIONS					
	This Analysis				**EIOLCA**		**This Analysis**		**EIOLCA**			
	Cost (US $ per ton)	% of total	Cost without Const., EOL, or Transp.	% without Const., EOL, or Transp.	Economic Activity (millions of $)	% of total	GHG Emissions (lbs CO_2-e per ton)	% of total	GHG Emissions (metric tons CO_2-e)	% of total	GHG Emissions without Power Gen.	% without Power Gen.
Extraction	$44.81	5.9%	$44.81	29.8%	0.037	2.8%	0.10	0.0%	0.0	0.0%	0.0	0.0%
Manufacturing	$105.62	14.0%	$105.62	70.2%	1.033	78.2%	786.07	95.4%	1350.0	70.6%	1350.0	96.9%
Construction	$526.88	69.8%					0.00	0.0%				
End of Life	$11.84	1.6%					0.04	0.0%				
Transportation	$65.16	8.6%					37.88	4.6%	10.3	0.5%	10.3	0.7%
Power Generation & Supply Chain					0.04	3.0%			517.9	27.1%		
Other					0.211	16.0%			33.5	1.8%	33.5	2.4%
TOTALS	$754.31	100.0%	$150.43	100.0%	1.321	100.0%	824.10	100.0%	1911.7	100.0%	1393.8	100.0%