2017

Pewabic Environmental Assessment

CENTER FOR SUSTAINABLE SYSTEMS

REES BLANCHARD

Acknowledgements

Pewabic
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Introduction

Pewabic is a not-for-profit ceramic studio and pottery school in Detroit, Michigan.[1] The organization employs full- and part-time ceramic artists and technicians to produce a variety of vessels and tiles, retailed on-site and from its online store.

Pewabic produces an estimated 1,000 square feet, about 3,400 kilograms, of ceramic tiles per month, including architectural field and gift tile.[2] The organization intends to increase production with support from the Erb Family Foundation.[3] The planned expansion will create an additional 2,500 square feet of storage and preparation space at the existing facility. The expansion will increase tile production by an estimated 80% from its current rate, to an average of 1,800 square feet of tile, or 6,120 kilograms per month (an additional 2,720 kilograms per month). With additional grant support from the Erb Family Foundation, Pewabic seeks to assess the environmental impacts associated with the expansion and determine next steps to improve the sustainability performance of the organization.

Objectives

This assessment quantifies environmental impacts associated with ceramic tile production and uses them to estimate the change in impacts resulting from the proposed Pewabic expansion. The primary objective of this study is to identify relevant environmental impacts and quantify them on a per-tile basis. This report summarizes key findings from the analysis and delivers recommendations on impact mitigation and future work.

Scope

The scope includes all activities and processes associated with the production of ceramic tile at Pewabic. The assessment focuses on energy, water, and materials use. Additionally, the assessment examines certain emissions and discharges to air, water, and soil resulting from on-site production. Impact categories selected for the assessment are materials use, water use, fossil energy, and greenhouse gas (GHG) emissions. The methods section provides more detail on impact categories and impact methods used in the assessment.

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[1] "Pewabic." From http://www.pewabic.org/ on 08/23/2017.
[2] Steve McBride, personal communication, July 18, 2017.
[3] Sigal Hemy. Personal communication, April 20, 2017.

Methods

Life Cycle Assessment (LCA) Approach
This assessment is not a full LCA study, though it follows a similar approach. The assessment examines tile production as a system of processes, from resource extraction (cradle) to retail of the finished product (gate). This assessment does not consider the end-of-life (grave) stage.

A major goal of the assessment is to build a life cycle inventory, a key component of a full LCA, for Pewabic ceramic tiles. The inventory catalogues all materials and energy uses associated with each stage of the product's life cycle. This assessment uses the LCA software *SimaPro* to construct an inventory for Pewabic gift or architectural field tile from cradle to gate, quantifying environmental impacts associated with tile production.

Presently, there is a dearth of literature on the environmental impacts of traditional ceramic pottery products. A scan of current literature identified a single life cycle assessment (LCA) of traditional ceramic plates for comparison.[4] The LCA study found that, *per kilogram*, the Sicilian ceramic plate of study requires 0.5 kg clay, 0.07 kg glaze, and 0.7 kg water. Cumulative energy demand was 20.5 MJ non-renewable (fossil) energy and GHG emissions associated with the life cycle are 1.3 kg CO_2e. Notably, the production phase represented 99% of life cycle impacts for fossil energy and GHGs.

Functional Unit
The assessment uses a functional unit, or basis for quantifying environmental impacts. The functional unit is 1 kilogram of tile, which facilitates scaling for the expansion scenario. Scaling up to the expected 80% increase in tile production would yield an additional 2,720 kilograms per month, representing the difference in production rates before and after the expansion. Using this method, impacts can be quantified for tiles produced as a result of the planned expansion.

Although this assessment assumes no functional difference between gift tile and architectural field tile, Pewabic tiles are not homogenous in their production processes and materials uses. For example, iridescent tiles are glazed with a special type of glaze and fired an extra (third) time in an electric kiln. These process differences likely result in varied environmental impacts across tile type. Therefore, this assessment averages all tile materials used, to provide a representative sample of materials used in tile production. Figure 1 (following page) illustrates the visual differences between iridescent and non-iridescent tiles.

[4] Giudice, A., et al. (2016) "Life cycle assessment for highlighting environmental hotspots in the Sicilian traditional ceramic sector: the case of ornamental ceramic plates." *Journal of Cleaner Production*, Vol. 142: 225-239.

Figure 1. Tile iridescence varies by firing and glazing process. Iridescent tile at left. Non-iridescent tile at right. *Images courtesy of Pewabic.*

Data Preference

The assessment relies on data provided by Pewabic about tile production and equipment usage. Analysis went into relating on-site process data to assessment impacts. Where primary data are not available, outside literature or data from SimaPro provide values for all processes involved in tile production.

Allocation

Many production processes are shared among pottery at Pewabic, necessitating an allocation for tile production. A mass-based allocation assigns materials, water, energy, and other facility-wide burdens to the production of ceramic tiles by mass (kilograms). This allocation is necessary to separate environmental burdens associated with other activities at Pewabic, like the production of ceramic vessels, from tile production. An example of a mass-based allocation equation for glaze materials used in ceramic tile is as follows:

$$M_{gt} = \Sigma (M_g) * (M_t / M_p)$$

where:
M_{gt} = glaze materials allocated to ceramic tile (kg)
M_g = glaze materials used in all tiles, vessels, and other pottery (kg)
M_t = mass of tiles (kg)
M_p = mass of all tiles, vessels, and other pottery (kg)

This equation allocates the fraction of total glaze materials used in ceramic tile by multiplying the sum of all glaze materials by the fraction of ceramic tile in all pottery in a given period of time. This allocation is necessary because Pewabic uses the same glazes for all types of pottery, as opposed to specific batches or types assigned to a different type of pottery. Summary tables of all data used in this assessment have been provided to Pewabic for their records, and are included in Appendix A.

Selection of Impact Categories

The assessment selects several impact categories to report for the functional unit, one kilogram of ceramic tile. As an impact assessment on a pottery studio, materials used in clays and glazes are of special concern. After materials, water, the Cumulative Energy Demand (CED) method was selected to determine the total amount of fossil energy required for the product system. Other impact categories are based on the EPA's Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI). [5] The primary focus of this assessment is on materials, energy, water use, and GHG emissions, but other impact categories observed in TRACI include eutrophication potential, acidification potential, ozone depletion potential, and human and ecotoxicity potentials. Appendix B contains definitions for each of these terms.

Materials Use

Materials in kilograms (kg) used to make ceramic tile were included above a minimum cut-off of 1% of dry input materials by weight for clays, and 1% of dry input materials by weight for glazes. Pewabic provided data used to calculate the average composition of tile clays and glazes. In the case of glazes, a mass-based allocation was used to assign material burdens to ceramic tile production.

Annual tile production (kg) was used as a basis for calculating energy burdens. The equation and corresponding calculation is as follows:

$W_a = S_t * W_s * (0.453592 \text{ lbs/kg})$

where:
S_t = square footage of tiles produced per year (feet^2/year)
W_s = weight of one square foot of tile (lbs)

Filling in the equation with other data collected in the assessment, the weight of tiles produced per year is:

$W_a = 11{,}000 \text{ ft}^2\text{/year} * 3.4 \text{ lbs} * 0.45359 \text{ lbs/kg} = 16{,}964.3408$ kg per year

Fossil Energy Use

Electricity and natural gas are used for clay making at Pewabic, to run electrical equipment and in the heating of kilns. Electrical energy comes from the electricity grid in the DTE Energy Company's service area. Energy consumption at Pewabic is also allocated by mass for ceramic tiles.

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[5] US Environmental Protection Agency. "Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI)." From https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci on 7/12/2017.

Transportation energy comes from fuel used for transport by truck from the distributor to Pewabic. Due to constraints on information, time, and resources, no other transportation scenarios are included. Future work could examine transportation of input materials from the mine or quarry to site of beneficiation or processing plant, as well as transportation from the plant to the distributor in Columbus, Ohio.

The CED method in SimaPro was used to quantify the energy used in production as well as all energy consumed throughout the supply chain. Additionally, this method takes into account upstream energy, or energy used to supply the energy required to create the product.

Water

Pewabic uses water in the mixing and preparation of clays and glazes. Clean water pressed out of the clay by filter press is discharged from the clay mixing process. The glaze making process involves a simple mixing that discharges no effluent to the environment. Based on this process examination, Pewabic does not discharge any effluents to water as a result of its pottery production. However, the clay making process uses a considerable amount of water. For that reason, water is included as a process input and quantified in this assessment.

GHG Emissions

GHGs are associated with energy use from electricity, natural gas, and fuel used in transportation, raw resource extraction. This assessment uses the TRACI impact assessment method to quantify GHG emissions, in kilograms of carbon dioxide equivalent (CO_2e) using global warming potential of individual GHG emissions.

Energy Use Calculations

Energy use data are needed to quantify energy consumption associated with tile production. At the onset of this assessment, Pewabic tracked energy use in the form of monthly utility bills for electricity and natural gas consumption. Individual kilns or pieces of electrical equipment are not metered separately, so more granular data are needed to understand energy burdens associated with specific processes. For that reason, electricity use (in kWh) was calculated by multiplying the equipment power (in Watts) by its average run time (in hours) over a given period. Electricity use was summed for all pieces of equipment over that period. A mass-based allocation was used to assign energy use burdens to ceramic tile production. Because the tile output is known over a given time period, electrical energy associated with tile production can be estimated as energy per kilogram tile.

The following page contains more detailed descriptions of the equations and calculations used to determine energy use per kg tile.

The equation and calculations below determine electricity use per kg tile.

$E_t = E_p + E_k = \Sigma (E_{equipment}) * (M_t / M_p) / W_a$

where:
E_t = Annual electricity consumption (kWh), summed electrical equipment (pre-firing and kilns)
E_p = Electrical energy of all pre-firing equipment (kWh)
E_k = Electrical energy of all kilns (kWh)
M_t = mass of tiles (kg)
M_p = mass of all tiles, vessels, and other pottery (kg)
W_a = annual tile production, calculated previously (kg)

Pewabic reported that the mass fraction of tiles (M_t / M_p) was 80% of all pottery production. Using numbers collected from the assessment, the calculations are as follows:

Pre-firing:	E_p = 5,574.11 kWh/year * 80% / 16,964.3408 kg/year = 0.2627 kWh
Kilns:	E_k = 28,154.88 kWh/year * 80% / 16,964.3408 kg/year = 1.3277 kWh
Total:	E_t = 33,728.99 kWh/year * 80% / 16,964.3408 kg/year = **1.5906 kWh**

Natural gas use associated with tile production was calculated differently from electricity use. The equation below shows the calculations made to determine natural gas use associated with tile production.

$G_{kt} = \Sigma (G_k) * (12 \text{ months}) * (N_t / N_a) * (M_t / M_p)$

where:
G_{kt} = Annual gas consumption associated with tiles (Ccf)
G_k = Monthly gas consumption from all kilns (Ccf)
N_t = Number of kilns that fire tiles and other vessels for retail
N_a = Number of all kilns, including those used for educational (non-retail) purposes
M_t = mass of tiles (kg)
M_p = mass of all tiles, vessels, and other pottery (kg)

Using numbers collected from the assessment, the calculation is as follows:

G_{kt} = 1,539 Ccf/month * 12 months/year * (18/22) =15,110.18 Ccf/year

Multiplying this number by the energy content of natural gas yields an annual gas use of 1,653,200.79 MJ.[6] Multiplying by the tile weight fraction, 80%, and dividing by 16,964.3408, the weight of tiles produced per year, yielded a natural gas use per kg tile of **77.96 MJ/kg**.

[6] Conversion factor of 109.41 MJ/Ccf from EIA. From https://www.eia.gov/tools/faqs/faq.php?id=45&t=8 on 08/01/2017.

Results

Using the functional unit of 1 kg of ceramic tile, an inventory and environmental impacts were quantified using the CED and the TRACI assessment methods. The following process flow chart was used to track stages of production to quantify environmental impacts associated with producing a kilogram of ceramic tile. Materials, water, energy use, and other impacts are reported below.

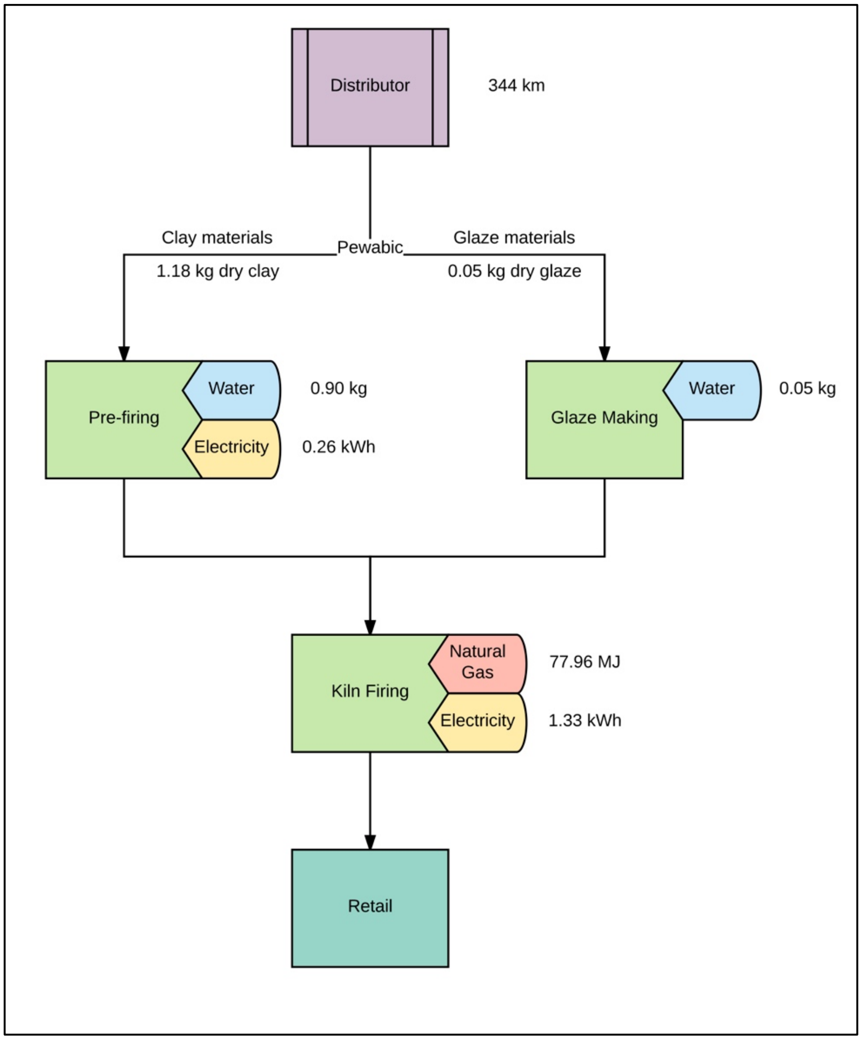

Figure 2. Simplified flow diagram for tile production process at Pewabic. The pre-firing stage includes clay mixing, shaping, pressing, and drying, while the kiln firing stage contains two to three firings, depending on the product. Glazing occurs between the first and second firing, while an optional third firing is added for iridescence.

One kilogram (kg) of ceramic tile requires 1.18 kg dry clay, 0.11 kg dry glaze, and 0.95 kg water as material inputs, and 110 MJ of fossil energy. Table 1 summarizes fossil energy use from CED, and Table 2 summarizes environmental impacts using the process types clay, glaze, natural gas, and electricity to demonstrate relative process contributions.

Table 1. CED Impacts

Impact category	Unit	Clay	Glaze	Natural Gas	Electricity	Total
Non-renewable, fossil	MJ	1.95	0.24	91.80	15.65	**109.64**
Non-renewable, nuclear	MJ	0.26	0.04	0.12	4.51	**4.93**
Non-renewable, biomass	MJ	0.00	0.00	0.00	0.00	**0.00**
Renewable, biomass	MJ	0.01	0.00	0.00	0.25	**0.27**
Renewable, wind, solar, geothermal	MJ	0.01	0.00	0.02	0.03	**0.05**
Renewable, water	MJ	0.02	0.01	0.01	0.03	**0.07**
All sources	MJ	2.25	0.29	91.95	20.47	**114.96**

Table 2. TRACI Impacts

Impact category	Unit	Clay	Glaze	Natural Gas	Electricity	Total
Ozone Depletion	kg CFC-11 eq	8.07E-09	1.75E-09	1.73E-09	5.72E-08	**6.87E-08**
GHG	kg CO_2 eq	0.140	0.018	5.297	1.450	**6.905**
Smog	kg O_3 eq	1.38E-02	1.74E-03	9.13E-02	8.04E-02	**1.87E-01**
Acidification	kg SO_2 eq	6.57E-04	1.82E-04	3.03E-03	9.24E-03	**1.31E-02**
Eutrophication	kg N eq	2.45E-04	3.38E-04	1.79E-04	5.62E-03	**6.38E-03**
Carcinogenics	CTUh	3.86E-09	3.49E-09	5.20E-10	8.65E-08	**9.44E-08**
Non-carcinogenics	CTUh	2.21E-08	7.46E-08	2.83E-09	2.85E-07	**3.85E-07**
Respiratory Effects	kg PM2.5 eq	2.95E-05	2.43E-05	9.08E-05	5.27E-04	**6.71E-04**
Ecotoxicity	CTUe	0.417	1.782	0.053	7.062	**9.31**
Fossil depletion	MJ	0.244	0.029	13.728	0.350	**14.350**

Tables 1 and 2 illustrate other impact categories not included in the scope of this assessment but present within the impact method, such as nuclear energy use and respiratory effects. For time and clarity, impact categories of focus in this report are fossil energy use (MJ) and GHG emissions (kg CO_2e), along with material and water consumption. Figure 3 illustrates GHG emissions and fossil energy.

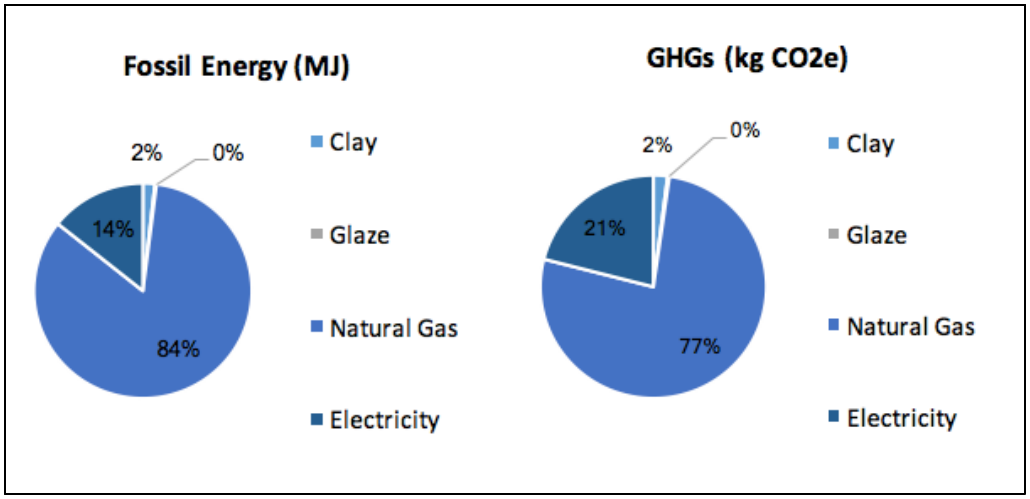

Figure 3. GHG emissions and fossil energy consumption for 1 kg of ceramic tile.

Natural gas is by far the largest contributor to GHG emissions and fossil energy use. Natural gas comprises 77% of the 6.9 kg CO_2e total GHG emissions and 84% of the total 109.6 MJ of fossil energy. Notably, while electricity is only 2% of fossil energy, it comprises 21% of the total GHG emissions. This disproportionate contribution is explained in the discussion section.

Materials inputs and environmental impacts are based on a kilogram of ceramic tile. Multiplying environmental impacts per kilogram allows the quantification of impacts given a larger quantity of tiles produced in a given time frame. For that reason, a spreadsheet containing the production quantity as a variable has been provided to Pewabic. The screen capture included in Figure 4 on the following page displays the quantity 2,720 kg tile the expected increase in monthly production resulting from the planned expansion. The spreadsheet displays the inputs of materials and water, and the environmental impacts for the GHG emissions and fossil energy impact categories. Tracking production quantity using this spreadsheet allows the user to vary production from month to month if the rate is not constant, or display impacts for a different time frame, such as a year of production. Additionally, other impact categories can be added to the spreadsheet if they are desired in future studies.

Production Amount						
Enter production quantity here ---->	2,720	*kg fired tile*	8636.3917	*square feet clay tile*		
Impact Summary						
	Clay	*Glaze*	*Natural Gas*	*Electricity*	*Total*	
Greenhouse Gas Emissions (kg CO2e)	380.09	48.31	14,406.87	3,945.27	18,780.54	<---- Total kg CO2e
Fossil Energy (MJ)	5,313.47	665.90	249,687.75	42,563.04	298,230.15	<---- Total MJ fossil energy

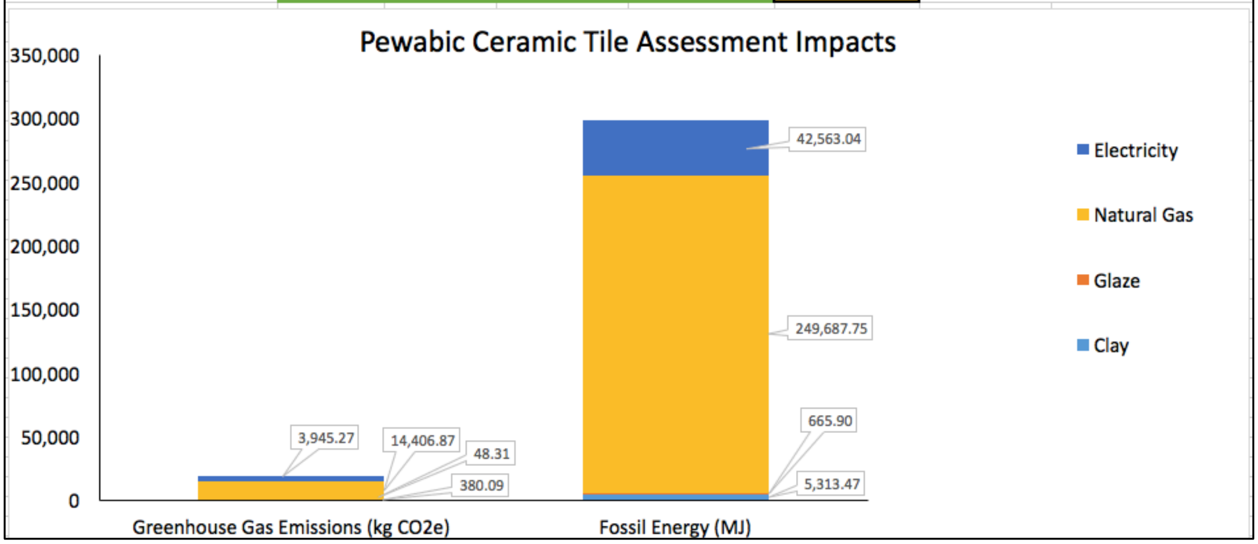

Figure 4. Screen capture of assessment impacts for 2,720 kilograms of ceramic tile. This quantity corresponds to the increased monthly production as a result of the expansion, which would increase tile output from 3,400 kg per month to 6,120 kg per month.

Four Scenarios

Changing the input parameters in the SimaPro model determined the sensitivity of results to some of the less certain data and assumptions made in the assessment. Four scenarios were examined to determine the effects of different assumptions on the overall results. The first scenario is the base scenario, which has already been presented earlier in this section. This scenario is reflective of the data collected at Pewabic and provides the most conservative results. Table 3 presents quantities for GHG emissions (kg CO_2e) and fossil energy use (MJ).

Table 3. Base impact assessment for GHG emissions and fossil energy for 1 kg ceramic tile

Impact category	Unit	Clay	Glaze	Natural Gas	Electricity	Total
GHG	kg CO_2e	0.140	0.018	5.297	1.450	**6.905**
Fossil Energy	MJ	1.953	0.245	91.797	15.648	**109.643**

The first test scenario increases the transportation distance by an order of magnitude. The base scenario used a distance of 344 kilometers from the distributor in Columbus, Ohio, to Pewabic in Detroit, Michigan. This scenario increases transportation distance to 3,444 kilometers. The intent of this scenario is not to suggest that the distributor is located farther away than it is, but instead to determine the effect of increasing transportation distance for the raw materials. The base scenario is conservative and does not include the unknown distance that raw materials must be transported to arrive at the distributor before being shipped to Pewabic. Table 4 shows the effect of increasing that distance by one order of magnitude for both impact categories.

Table 4. 10X Transportation Distance for 1 kg ceramic tile

Impact category	Unit	Clay	Glaze	Natural Gas	Electricity	Total
GHG	kg CO_2e	0.731	0.048	5.297	1.450	**7.526**
Fossil Energy	MJ	10.013	0.664	91.797	15.648	**118.122**

As shown in Table 4 above, both GHG emissions and fossil energy increase slightly, remaining in the same order of magnitude as the base scenario. A 100X scenario is not included because 34,440 kilometers seems an unrealistic distance for transportation by truck. For comparison, the circumference of the Earth is 40,074 kilometers.

The second test scenario examines the uncertainty in some of the materials selected for the glaze. Pewabic has a list of materials in its glazes, many of which have entries in the SimaPro database. Several substitutions for unlisted materials were made, and are documented in Appendix A of this report. Because this substitution created uncertainty, the amounts of all materials used in glazes are increased by orders of magnitude to determine the strength of the effect on the two impact categories. Multiplying each of the quantities by ten did not change either of the impacts, so it can be concluded that the uncertainty around specific quantities of glaze is relatively inconsequential. However, when the quantities of glaze materials are increased by two orders of magnitude (results in Table 5), glaze becomes a greater driver of impacts than clay and electricity. This scenario is unrealistic as the individual quantities of most of the glaze materials required are greater than the total amount of glaze or clay used to produce the functional unit. It should also be noted that analysis of substitutions of input materials yields little change to the total impact when different processes are selected.

Table 5. 100X Glaze Materials for 1 kg ceramic tile

Impact category	Unit	Clay	Glaze	Natural Gas	Electricity	Total
GHG	kg CO_2e	0.1397	1.4372	5.2966	1.4505	**8.324**
Fossil Energy	MJ	1.953	19.865	91.797	15.648	**129.264**

The last test scenario examines the disproportionate GHG impact of the electricity grid. As previously stated, although electricity accounts for only 2% of fossil energy consumption, it represents 21% of GHG emissions. Table 6 shows the effect of changing the assumed electricity grid fuel mix from that reported by DTE Energy (roughly ¾ coal) to an electricity supplier sourcing 100% of its energy from wind.

Table 6. 100% Wind Power for 1 kg ceramic tile

Impact category	Unit	Clay	Glaze	Natural Gas	Electricity	Total
GHG	kg CO_2e	0.1397	0.0178	5.2966	0.0179	**5.472**
Fossil Energy	MJ	1.953	0.245	91.797	0.231	**94.226**

Table 5 shows the effect of reducing the carbon intensity of the electricity grid. Both impacts are reduced slightly, although not quite as markedly as might be expected. This lack of significant change is due to the huge relative effect of natural gas, which in the base scenario comprises 77% of GHGs and 84% of fossil energy consumption. This scenario is not entirely fictitious as it could represent an energy procurement contract in which Pewabic agrees to offset all electricity it consumes with renewable energy sourced from a wind farm, for example.

Discussion

Data collected at Pewabic were all considered high quality. That said, some data came with a degree of uncertainty. For example, the rate of production was taken to be a fixed constant but it was also acknowledged that production varies from month to month. Uncertainty around production quantity is resolved through the functional unit of 1 kg ceramic tile. By quantifying all inputs and impacts on a per kilogram basis. By multiplying the tile quantity using the spreadsheet provided, Pewabic can quickly assess the impacts of a different rate of production.

Transportation scenarios represent a source of unresolved uncertainty. The 10X transportation scenario presents one example of how increasing the distance driven to transport the materials by an order of magnitude increases GHG emissions and fossil energy impacts. While multiplying distances for raw materials may seem unrealistic, the key takeaway from this analysis is that there could be a significant change in impact, but it is presently unknown due to uncertainty in the distances from materials suppliers to the distributor in Columbus, Ohio.

The contribution of the electricity grid to GHG emissions is another topic for discussion. This assessment uses information provided by DTE Energy on its electricity grid fuel mix. However, given a different fuel mix composition, as shown in the 100% Wind Power scenario, GHG emissions can change significantly. However, while the relative contribution to GHG emissions decreases by shifting away from coal-based electricity, its effect in absolute terms is drowned out by natural gas use, the dominant driver of GHG emissions.

Results from the Giudice et al. study are different, but may be indirectly relatable. Impacts of fossil energy and GHG emissions were much lower, at 20.5 MJ fossil energy and 1.3 kg CO2e. Pewabic's impacts were 109.6 MJ fossil energy and 6.9 kg CO2e. While the amounts differed, the ratios were comparable. Pewabic ceramic tile used roughly 15 times more kg CO2e and MJ fossil energy than the ornamental ceramic plate in Giudice et al. The two products are notably different, so their different impacts are not surprising, but it is interesting to note the ratio of MJ/kg CO2e is roughly constant, at 15.77 for Giudice et al. and 15.88 for this assessment. The observed relationship between fossil energy and GHGs is understandable—GHG emissions scale with fossil energy use.

As in the Giudice et al. study, at Pewabic energy used for kiln firing dominates most impact categories. It should be noted that differences exist in the types of kilns and energy used in production, so direct comparison is inappropriate. Similarly, material uses differ due to different product types and choices in glazes. Pewabic tile uses more input material per finished kilogram. It should be noted that over twice the amount of wet clay, 2.06 kilograms, goes into one kilogram of fired tile. One explanation for this discrepancy is that the measurement of wet clay inputs did not account for the clay that is removed and reclaimed during the pressing process, and is therefore likely to be an overestimate.[7]

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[7] Steve McBride, personal communication, September 15, 2017.

Conclusion

This assessment begins by identifying impact categories for the functional unit of one kilogram of ceramic tile. It was found that 1 kilogram (kg) of ceramic tile requires 1.18 kg dry clay, 0.11 kg dry glaze, and 0.95 kg water. In addition to requiring those material and water inputs, the production of one kilogram of ceramic tile at Pewabic uses 109.64 MJ fossil energy and releases 6.91 kilograms CO_2 equivalent. These impacts are quantified on a per kilogram basis to enable Pewabic to track its ongoing impacts as it ramps up production after the planned expansion.

Several scenarios are explored to test the uncertainty around data and determine the effects of changing input parameters. Natural gas consumption for kiln firing dominates fossil energy use and GHG emissions across all scenarios tested. Natural gas use increases with kiln firings so it is unlikely to decrease as production output ramps up at Pewabic. However, fossil energy and GHG emissions are similarly correlated with a study conducted on LCA of ornamental ceramic plates. In both the cited study and this assessment, kiln firing is the dominant driver of environmental impacts.

Generally, areas of improvement that build on this assessment would fill information gaps where there are greater degrees of uncertainty. Studies that dive deeper into Pewabic's supply chain would enhance this assessment by providing more clarity on the materials used in clays and glazes. Further work could build on this assessment by exploring other scenarios to reduce the impacts documented by this assessment. For example, the wind power scenario brought down GHG emissions and fossil energy by a small amount. Implementation of other technologies could potentially see even greater improvements in Pewabic's environmental performance.

The analysis conducted in this assessment is intended to help to further Pewabic's environmental and sustainability goals, in addition to laying the groundwork for follow-up studies and environmental reporting initiatives. Specific recommendations on topics of future work are detailed in the next section.

Recommendations for Future Work

LCA
This initial assessment could be taken several steps farther by building on the existing assessment model to conduct a full LCA study. Much of this assessment depends on data collected at Pewabic, which have been organized into a single spreadsheet. A future LCA could build on the existing data while pursuing a deeper exploration of Pewabic's supply chain. Specific information gaps are transportation, which currently only includes the link from distribution to the facility, and raw materials for which substitutes were made in the analysis. Additional stages considered outside the scope but perhaps of concern are end-of-life and disposal scenarios, as well as retail and shipping from Pewabic to customers.

Green Squared (G^2)
Pewabic could consider pursuing the Green Squared (G^2) certification for its ceramic tiles. This certification would encourage the use of Pewabic tiles in LEED certified projects,[8] as well as provide documentation of steps taken to improve the organization's environmental performance. This assessment has already identified and contributed to those steps needed to obtain certification, including contribution to a life cycle inventory for ceramic tiles. Further credit can be earned through participation in a full LCA study. Appendix A contains more information on the G^2 certification program and a checklist for obtaining the certification label.

Master's Project at the School for Environment and Sustainability (SEAS)
From 2016 to 2017, Pewabic worked with the University of Michigan's School of Natural Resources and Environment (now School for Environment and Sustainability) on a Master's Project in Landscape Architecture.[9] Given the current expansion work and the scope of future environmental work, Pewabic could sponsor a new Master's Project to build on the work from this assessment. Ideally, the project would assist Pewabic's environmental data collection and measurement efforts. The project team could even follow up on obtaining the G^2 Certification, and develop and execute their own plan to improve environmental performance or sustainability reporting within the organization.

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[8] Green Squared (G^2). "Green Squared: The Standard for Tiles and Installation Materials." From http://www.greensquaredcertified.com/green-blog/193-green-squared-certified-sustainable-tiles-and-tile-installation-materials-qualify-for-new-leed-credit.html on 08/25/2017.

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Appendix A: Data Tables and Inputs for SimaPro

The following collection of data represents information gathered at Pewabic and organized for this assessment.

Table 7. Transportation distance

Name	Quantity	Unit	Type	Coverage	Use in Assessment
Distance from distributor	344	km	distance	per kg material	Transport from distributor to Pewabic

Table 8. Clay batch information

Name	Quantity	Unit	Type	Coverage	Use in Assessment
Dry materials per batch	2,300	lbs	mass	per batch	Amount dry mtls input
Water per batch	210	gal	volume	per batch	Amount water input
Unfired clay output per batch	4,000	lbs	mass	per batch	Amount output (clay and water)

Table 9. Glaze materials

Name	Quantity	Unit	Type	Coverage	Use in Assessment
FLINT 325M	350	lbs	mass	6-8 weeks	Average composition (1% or greater)
OM-4 BALL CLAY	300	lbs	mass	6-8 weeks	Average composition (1% or greater)
CUSTER FELDSPAR	250	lbs	mass	6-8 weeks	Average composition (1% or greater)
BARIUM CARBONATE	250	lbs	mass	6-8 weeks	Average composition (1% or greater)
NEPHELINE SYENITE A-270	250	lbs	mass	6-8 weeks	Average composition (1% or greater)
WHITING	200	lbs	mass	6-8 weeks	Average composition (1% or greater)
GILLESPIE BORATE	150	lbs	mass	6-8 weeks	Average composition (1% or greater)
WOLLASTONITE	100	lbs	mass	6-8 weeks	Average composition (1% or greater)
EPK KAOLIN	50	lbs	mass	6-8 weeks	Average composition (1% or greater)
MINSPAR-200	50	lbs	mass	6-8 weeks	Average composition (1% or greater)
TALC	50	lbs	mass	6-8 weeks	Average composition (1% or greater)
LITHIUM CARBONATE	50	lbs	mass	6-8 weeks	Average composition (1% or greater)
Copper carbonate	50	lbs	mass	6-8 weeks	Average composition (1% or greater)
Red iron oxide	50	lbs	mass	6-8 weeks	Average composition (1% or greater)
DOLOMITE	25	lbs	mass	6-8 weeks	Average composition (1% or greater)
FERRO FRIT #3110	25	lbs	mass	6-8 weeks	Average composition (1% or greater)
Glaze material total weight per order	2250	lbs	mass	6-8 weeks	Average composition (1% or greater)

Table 10. Tile making

Name	Quantity	Unit	Type	Coverage	Use in Assessment
Tile fraction of all production	80%		percent	per year	Assign tile burden for electricity and NG consumption
Weight of 1 square foot wet tile	7	lbs	mass	per sq. ft tile	Determine weight per ft2
Weight of 1 square foot fired tile	3.4	lbs	mass	per sq. ft tile	Determine weight per ft2
Square feet of tile produced per batch	250	ft^2	area	per batch	regular tile production
Square feet of tile produced per year	11,000	ft^2	area	per year	annual tile production

Table 11. Pre-firing electrical equipment

Name	Quantity	Unit	Type	Coverage	Use in Assessment
air compressor, power	1.5	hp	power	equipment power	Production electrical energy
air compressor, time	40	hours	time	average run time per week	Production electrical energy
glaze mixer, power	0.75	hp	power	equipment power	Production electrical energy
glaze mixer, time	5	hours	time	average run time per week	Production electrical energy
15 ton ram, power	2	hp	power	equipment power	Production electrical energy
15 ton ram, time	16	hours	time	average run time per week	Production electrical energy
30 ton ram, power	3	hp	power	equipment power	Production electrical energy
30 ton ram, time	16	hours	time	average run time per week	Production electrical energy

Table 12. Firing energy

Name	Quantity	Unit	Type	Coverage	Use in Assessment
Blaauw kiln, power	7200	W	power	equipment power	Production electrical energy
Blaauw kiln, time	24	hours	time	average run time per week	Production electrical energy
BBL kiln, power	7200	W	power	equipment power	Production electrical energy
BBL kiln, time	24	hours	time	average run time per week	Production electrical energy
Geil kiln, power	1200	W	power	equipment power	Production electrical energy
Geil kiln, time	12	hours	time	average run time per week	Production electrical energy
Evenheat kiln, power	15120	W	power	equipment power	Production electrical energy
Evenheat kiln, time	12	hours	time	average run time per week	Production electrical energy
Natural gas use	1539	Ccf	volume	per month	Gross NG consumption
Tile production kilns	18		count	equipment	For allocation to tile production
All kilns	22		count	equipment	For allocation to tile production
Energy content NG	109.41	MJ	energy	per Ccf	For allocation to tile production

Table 13. Average electricity grid fuel mix from DTE[10]

Name	Quantity	Type	Coverage	Use in Assessment
Coal	74.09%	percent	Annual	Impacts related to electricity use
Nuclear	17.14%	percent	Annual	Impacts related to electricity use
Gas	3.62%	percent	Annual	Impacts related to electricity use
Oil	0.23%	percent	Annual	Impacts related to electricity use
Hydroelectric	0.16%	percent	Annual	Impacts related to electricity use
Renewable Fuels Total	4.76%	percent	Annual	Impacts related to electricity use
Biofuel	0.08%	percent	Annual	Impacts related to electricity use
Biomass	1.05%	percent	Annual	Impacts related to electricity use
Solar	0.03%	percent	Annual	Impacts related to electricity use
Wind	3.19%	percent	Annual	Impacts related to electricity use
Wood	0.08%	percent	Annual	Impacts related to electricity
Solid Waste Incineration	0.32%	percent	Annual	Impacts related to electricity

Table 14. Inputs for SimaPro

Process	Amount	Unit
Pewabic Clay	2.058823529	kg
Pewabic Glaze	0.106995102	kg
Combustion of natural gas, consumption mix, at plant/NL Mass	77.96121578	MJ
Pewabic, DTE Electricity mix/US U	1.590582877	kWh

Table 15. Inputs for SimaPro, Pewabic Clay (1 kg)

Process	Amount	Unit	Comment
Clay, at mine/CH U	0.2999775	kg	Combined fireclay, ball clay
Kaolin, at plant/RER U	0.1500175	kg	Combined kaolin and mullites
Feldspar, at plant/RER S	0.07498	kg	
Silica sand, at plant/DE U	0.050025	kg	
Tap water, at user/CH U	0.43812825	kg	
Transport, combination truck, average fuel mix/US	0.344	tkm	

[10] DTE Energy's average fuel mix, 2013. From https://www2.dteenergy.com/wps/portal/dte/aboutus/environment/details from 08/13/2017.

Table 16. Inputs for SimaPro, Pewabic Glaze (1 kg)

Process	Amount	Unit	Comment
Clay, at mine/CH U	0.068504635	kg	
Feldspar, at plant/RER S	0.13130055	kg	Combined Custer feldspar, Minspar-200, Nepheline-syenite, and Ferro Frit #3110
Silica sand, at plant/DE U	0.079922074	kg	Substituted Flint 325M with Silica sand
Lithium carbonate, at plant/GLO U	0.011417439	kg	
Borax, anhydrous, powder, at plant/RER U	0.034252317	kg	Substituted Gillespie borate with borax
Vermiculite, at mine/ZA U	0.011417439	kg	Substituted talc with vermiculite
Barite, at plant/RER U	0.057087196	kg	Substituted barium carbonate with barium sulfate (barite)
Limestone, milled, packed, at plant/CH U	0.068504635	kg	Combined whitings (calcium carbonate) and wollastonite (calcium silicate)
Iron ore, 65% Fe, at beneficiation/GLO U	0.011417439	kg	Substituted iron oxide with iron ore
Copper carbonate, at plant/RER U	0.011417439	kg	
Kaolin, at plant/RER U	0.011417439	kg	Substituted standard kaolin for Edgar Plastic Kaolin (EPK)
Dolomite, at plant/RER U	0.00570872	kg	
Tap water, at user/CH U	0.48621524	kg	
Transport, combination truck, average fuel mix/US	0.344	tkm	

Table 17. Inputs for SimaPro, electricity grid (1 kWh)

Process	Amount	Unit
Electricity, hard coal, at power plant/US U	0.7409	kWh
Electricity, nuclear, at power plant/US U	0.1714	kWh
Electricity, natural gas, at power plant/US U	0.0362	kWh
Electricity, production mix photovoltaic, at plant/US U	0.0023	kWh
Electricity, hydropower, at power plant/SE U	0.0016	kWh
Renewable Fuels Total	0.0476	kWh
Biofuel	0.0008	kWh
Biomass	0.0105	kWh
Solar	0.0003	kWh
Wind	0.0319	kWh
Wood	0.0008	kWh
Solid Waste Incineration	0.0032	kWh

Appendix B: TRACI Impact Method

The Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) is an environmental impact tool created by the US EPA, providing characterization factors for life cycle impact assessment. The TRACI user manual contains helpful definitions for each of the impacts used in this report.[11] A brief explanation of TRACI methods, characterization factors, and definitions of impact categories are provided below.

TRACI calculates most impact categories using the following generalized equation:

$$I^i = \Sigma_{xm} (CF^i_{xm} * M_{xm})$$

Where:
I^i = the potential impact of all chemicals (*x*) for a specific impact category of concern (*i*)
CF^i = the characterization factor of chemical (*x*) emitted to media (*m*) for impact category (*i*)
M_{xm} = the mass of chemical (*x*) emitted to media (*m*)

Characterization factors apply to the following media for each impact category:

Table 18. Media affected by TRACI characterization factors by category

Impact Category	Media
Ozone Depletion	Air
Global Climate	Air
Acidification	Air, Water
Eutrophication	Air, Water
Smog Formation	Air
Human Health Particulate	Air
Human Health Cancer	Urban Air, Nonurban Air, Freshwater, Seawater, Natural Soil, Agricultural Soil
Human Health Noncancer	Urban Air, Nonurban Air, Freshwater, Seawater, Natural Soil, Agricultural Soil
Ecotoxicity	Urban Air, Nonurban Air, Freshwater, Seawater, Natural Soil, Agricultural Soil

[11] US Environmental Protection Agency. “Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1: User’s Guide.” From https://nepis.epa.gov/Adobe/PDF/P100HN53.pdf on 08/24/2017.

Acidification

Sulfur dioxide (SO_2) and nitrogen oxides (NO_x) react with water vapor in the atmosphere and give rise to acid rain, which damages both natural systems and human development. Acidification, or acidification potential, can be expressed in terms of kg SO_2 equivalent.

Eutrophication

Eutrophication, or the enrichment of an aquatic environment with nutrients like nitrogen (N) and phosphorus (P) from sewers and agricultural runoff, can have unintended consequences like the harmful algal blooms in Lake Erie and the Gulf of Mexico.[12] Eutrophication, or Eutrophication Potential, can be quantified in terms of kg N equivalent.

Global Climate Change

GHGs contribute to climate change by preventing the escape of solar radiation reflected from the Earth. The relative contributions to climate change of anthropogenic emissions of carbon dioxide (CO_2), methane (CH_2), nitrous oxide (N_2O), and other compounds can be combined using a common factor, conventionally called global warming potential. GHG emissions are quantified and reported in terms of kg CO_2 equivalent.

Ozone Depletion

Ozone in the stratosphere provides protection from certain types of solar radiation, which can lead to cancer and cataracts in humans, as well as having harmful consequences to animal and plant life. Chlorofluorocarbons (CFCs) have been linked to the depletion of the stratospheric ozone layer. Ozone depletion, or Ozone Depletion Potential, can be quantified in terms of kg CFC-11 equivalent.

Human Health Particulate (Respiratory Effects)

Certain small particles in the air cause adverse human health effects including respiratory illness and death. Sensitive populations like children, the elderly, and people with asthma, are more likely to experience higher consequences as a result of exposure to particulate matter. Respiratory effects are expressed in terms of "inhalable fine particles," or kg PM2.5 equivalent (2.5 micrometers or less).

[12] U.S. Department of Commerce: National Oceanic and Atmospheric Administration (2017) "Harmful Algal Blooms: Tiny Plants with a Toxic Punch." From http://oceanservice.noaa.gov/hazards/hab/ on 06/23/2017.

Human Health Cancer, Noncancer, and Ecotoxicity

USEtox, a global consensus model, was used to develop human health cancer and noncancer toxicity potentials and freshwater ecotoxicity potentials for over 3000 substances including organic and inorganic substances. The USEtox model quantifies toxicity in terms of Comparative Toxic Units (CTU): *CTUcancer* for carcinogenics, *CTUnoncancer* for non-carcinogenics, and *CTUeco* for ecotoxicity.[13] In this report, CTUh refers to toxicity to humans, and CTUe refers to ecotoxicity.

Photochemical Smog Formation

Interactions between nitrous oxides (NO_x) and volatile organic compounds (VOCs) create ground-level ozone, which forms smog. A variety of respiratory issues can be exacerbated from exposure to smog including symptoms of bronchitis, asthma, and emphysema. Prolonged exposure to ozone can result in permanent lung damage in humans and ecological impacts like harm to ecosystems and crops. Smog Potential can be quantified in terms of kg Ozone (O_3) equivalent.

Fossil Energy Use

This impact category is a cumulative sum of all the non-renewable energy needed throughout a product's life cycle. Fossil fuel, or fossil energy use, is quantified in terms of megajoules (MJ). It should be noted that while TRACI uses a "fossil depletion" impact category, representing the burden of replacing nonrenewable resources, that category does not reflect the cumulative energy demand of the product system. For that reason, the method Cumulative Energy Demand was selected instead to represent all non-renewable energy use throughout the product system.

[13] USEtox. "USEtox User Manual." From http://www.usetox.org/sites/default/files/support-tutorials/user_manual_usetox.pdf on 08/24/2017.

Appendix C: Green Squared (G^2) Certification[14]

The Green Squared Certified certification mark exists to differentiate products that meet the ANSI A138.1 standard and have been certified by a third party recognized by the Tile Council of North America. Once a third party is satisfied that the product in question conforms to the requirements of the Green Squared certification program, the manufacturer may use the Green Squared Certified certification mark on that product.

A product labeled with the Green Squared Certified certification mark must be assessed by a recognized third-party certification body for conformance to the American National Standards Institute (ANSI) A138.1 American National Standard Specifications for Sustainable Ceramic Tiles, Glass Tiles and Tile Installation Materials. Certification bodies ensure that products conform to the standard, authorizing the use of the Green Squared Certified certification mark for a certified product only.

The standard criteria defined by the ANSI A138.1 determine whether a product can be certified. To qualify, a certified product need not meet all aspects of the ANSI A138.1 standard. Instead, the certification body will evaluate the product and award points based on the number and type of criteria met. Any product above a certain threshold will be authorized the use of the Green Squared Certified certification mark for a period of time.

Once the TCNA has authorized use of the Green Squared certification mark, the manufacturer may use the certification mark on product packaging or directly on the product. The mark may not be used on products that have not met the requirements of the Green Squared certification program. The manufacturer may also publish its authorization to use the Green Squared Certified certification mark on certified products in promotional literature, but it may not suggest Green Squared Certified labeling of other products or the manufacturer as an entity. The Green Squared Certified certification mark logos may be rendered in color or plain black, and rendered in any size that maintains original aspect ratios, but may not be cropped or altered in any way.

After certification, the manufacturer must send the certification body any information required to conduct a surveillance audit verifying that the product continues to conform to ANSI A138.1. An on-site visit may be required in the event of possible non-conformance, such as mark misuse or changes in product formulation. In addition, certified products must be resubmitted for certification every three years.

Conformance with ANSI A138.1

Eligible products include ceramic and glass tiles (mosaic, quarry, pressed floor, glazed wall, porcelain, and specialty tiles), as well as tile installation materials. A product is considered in conformance with ANSI A138.1 and therefore eligible for Green Squared certification if all

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[14] Tile Council of North America. "Green Squared Certification Program." 2011

mandatory criteria are satisfied and the number of elective credit units (CUs) earned exceeds the required threshold for each product type. Appendix A of the source document details the scoring tool used to determine product certification.

Mandatory Criteria – Checklist for Certification

- ❑ **Recycled or reclaimed content**: Level 1 must be met; additional 1 CU may be rewarded for Level 2, 2 CU for Level 3

- ❑ **Indigenous raw materials**: elective CU may be rewarded for Level 1; 2 CUs for Level 2; 3 CUs for Level 3; manufacturer must maintain an organized list of addresses for suppliers and provide information on transportation modes and shipping logistics.

- ❑ **Packaging**: the manufacturer must meet at least one of the packaging electives, indicate the elective to the certifier, and provide the relevant documentation where needed. All five elective options are as follows:

1. *Minimal packaging*: provide calculations demonstrating package weight values within the ranges expressed for each product type in ANSI A138.1.
2. *Recyclable packaging*: provide calculations demonstrating that the required percentage of packaging material is recyclable. The appropriate recycling classification mark must also be printed on the packaging, and demonstrated to the certifier.
3. *On-site reusable packaging*: demonstrate that drawings or descriptions of on-site reuse possibilities are printed on the packaging.
4. *Biodegradable packaging*: documentation from the packaging material supplier that packaging is in conformance with relevant biodegradability standards.
5. *Packaging with recycled content*: a letter from the packaging material supplier demonstrating recycled content level of that material.

- ❑ **Product durability**: Lab reports and necessary documentation submitted to the certifier must demonstrate that the product meets ANSI A138.1. The manufacturer must demonstrate evidence of a quality assurance program to guarantee continued conformance with relevant product standards.

- ❑ **Product emissions criteria**: As per the ANSI A138.1 guidelines, emissions criteria vary by product type. No additional testing or documentation is needed if the manufacturer provides documentation that the tile has no post-fire adhesive, wax, or organic coating.

- ❑ **Cleaning and environmental maintenance**: Documentation of comprehensive maintenance instructions routinely sent to the consumer for the product of interest.

- ❑ **Pollution prevention to reduce particulates**: Title V documentation as required by the local EPA pollution control agency to demonstrate no visible emissions from buildings containing process equipment. Buildings with process equipment that control particulate emissions must have control equipment such that all PM emissions do not exceed 0.05 grams per dry standard cubic meter (g/dscm) for all dust collection systems. An elective 1 CU may be given for PM emissions less than or equal to 0.032 g/dscm; 2 CUs given for all PM emissions less than or equal to 0.005 g/dscm of its dust collection systems. Stack testing results provided to the certifier must demonstrate compliance above elective CUs.

- ❑ **Fuel usage**: The manufacturer must provide the certifier gas bill(s) associated with all combustion units used in the manufacture of the product of interest. Allowable fuel types are: natural gas, LP gas, landfill generated methane, or bio-based fuel. Elective 1 CU awarded for documented evidence each of the following: landfill generated methane fuel used in one or more of the combustion units, bio-based fuel used in one or more of the combustion units, low NOx burners in at least 50% of natural gas or LP gas units.

Elective Criteria

- ❑ **High solar reflectance index (SRI)**: 1 CU for a tile with an SRI value of 29 or greater; 2 CUs for SRI values greater than or equal to 78. These values are common for exterior surfacing.

- ❑ **High light reflectance value (LRV)**: 1 CU for an LRV of 70% or greater. High LRVs are typical of interior surfacing products to increase ambient brightness and reduce the need for lighting. To award this CU, the certifier requires documentation or test reports demonstrating the product was tested in accordance with ASTM C609 and received an LRV of 70% or greater.

- ❑ **Sound abatement characteristics**: 1 CU for a material product that has ΔIIC value of 10 or greater when tested according to ASTM E2179. Documentation demonstrates an improvement in impact insulation class of 10 or greater.

- ❑ **Participation in life cycle evaluation initiatives**: Elective CUs are awarded for products in conformance with the following life cycle evaluation work:

1. *ISO 14040/14044 Life Cycle Assessment (LCA)*: Up to 2 CUs if an LCA report is written for the product of interest or its product line. The certifier must receive the LCA report, conducted by a third party or in-house in conformance with ISO 14040/14044 using a standard LCA tool, such as SimaPro, Athena EIE, or US EPA TRACI.
2. *ISO 14025 Environmental Product Declaration (EPD)*: 1 CU for an EPD of the product of interest, in conformance with ISO 14025. The EPD utilizes LCA findings and shall be administered by an EPD Program Operator in conformance with section 6.3 of ISO 14025.
3. *Contribution to LCA software modules and general Life Cycle Inventory (LCI) Database Project participation*: 1 CU if a product is included in Building for Economic and Environmental Sustainability (BEES), an end user LCA tool by the National Institute of Standards and Technology (NIST). The inclusion could expand the number of tile industry products available to end users and contribute to the US LCI Database Project.