GHG Emission Reduction Methodology for the Sioneer Facility in Stockton, CA

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The proposed project will result in permanent and measurable reduction in greenhouse gas (GHG) emissions from the handling and landfilling of mixed broken glass by **diverting this waste material from the landfill and recycling it into a glass pozzolan for use as a cement replacement in concrete products**.

Introduction to Glass as a Pozzolan

The production of portland cement, which is the most commonly used cement in the world, releases approximately 0.88 tons of CO_2 per ton of cement produced (EPA 2015), and is reported to be responsible for 5-8% of global anthropogenic carbon emissions annually (Scrivener and Kirkpatrick 2008). By replacing portions of the portland cement in concrete with a glass pozzolan, significant greenhouse gas emission reductions can be achieved.

A pozzolan is the term given to a material that, when combined with portland cement and water, forms cementitious phases. The incorporation of a quality pozzolan can also significantly improve the durability of concrete products (Kosmatka and Wilson 2011, Obla, Neal et al. 2012), thereby saving time, energy, materials, and maintenance and replacement costs over the life of the product. Currently, fly ash, slag, and silica fume are the most commonly used types of pozzolans. Most ready mixed concrete produced in the United States contains some fraction of fly ash or slag (Obla, Lobo et al. 2012). Chemically, ground glass is comparable to Class F fly ash, where the sum of the oxides, SiO_2, Al_2O_3, and Fe_2O_3, is often over 70%. However, as a commonly used consumer product, it offers wider geographic availability than fly ash, which must be transported from electric power plants, or slag, which is only available where iron or steel is manufactured.

The majority of ground glass produced in the United States is soda lime glass, which means most waste glass streams offer a more consistent chemical composition than fly ash, which can vary significantly from source to source. This consistent composition is extremely important in the manufacture of concrete products, as reliability and reproducibility are held paramount within the industry. The prediction of material performance is important to life safety when building products are concerned. There is a great deal of research substantiating the positive effects of using ground glass powder as a pozzolan in concrete (Shi, Wu et al. 2005, Shayan and Xu 2006, Shi and Zheng 2007, Idir, Cyr et al. 2011).

Narrative of the SiONEER Glass Pozzolan Production Plan

Currently, in the Bay area, post-consumer materials from single stream curbside recycling programs, including glass, are collected and transported to a material recycling facility (MRF) for sorting. At the MRF, the glass is separated out from the rest of the municipal solid waste materials and transported to a glass processor. In some cases, the mixed color, broken glass at the MRF is further separated into fines (less than 3/8” in size), and then only the larger mixed color, broken glass goes to the glass processor. In either case, the glass that arrives at the glass processor undergoes a cleaning and sorting process to remove the cullet suitable for use in the manufacture of new glass. The clean, sorted glass is transported to the new glass manufacturer, leaving behind the fines or other unsorted glasses. These fines or unsorted glasses, collected at the glass processor, or sometimes at the MRF, are transported to a landfill for disposal.

What makes the SiONEER Glass Pozzolan (SGP) manufacturing process unique is that it will process the MRF glass as above, and also refine the fines and other unsorted glass into valuable commodities. The glass initially destined for the landfill can now be transported to the nearby SiONEER CleanGlass Plant, where it will undergo an initial grinding process, a sanitization treatment process, a drying process, and a final grind. The resulting material will be a fine glass powder, which can be transported to a concrete manufacturer for use as a pozzolanic portland cement replacement. This process is further illustrated in the flowchart in Figure 1, where the SiONEER process is boxed in green. The blue boxes represent the current glass-recycling loop, and the gray boxes indicate the flow of waste fines and unsorted glass to the landfill.

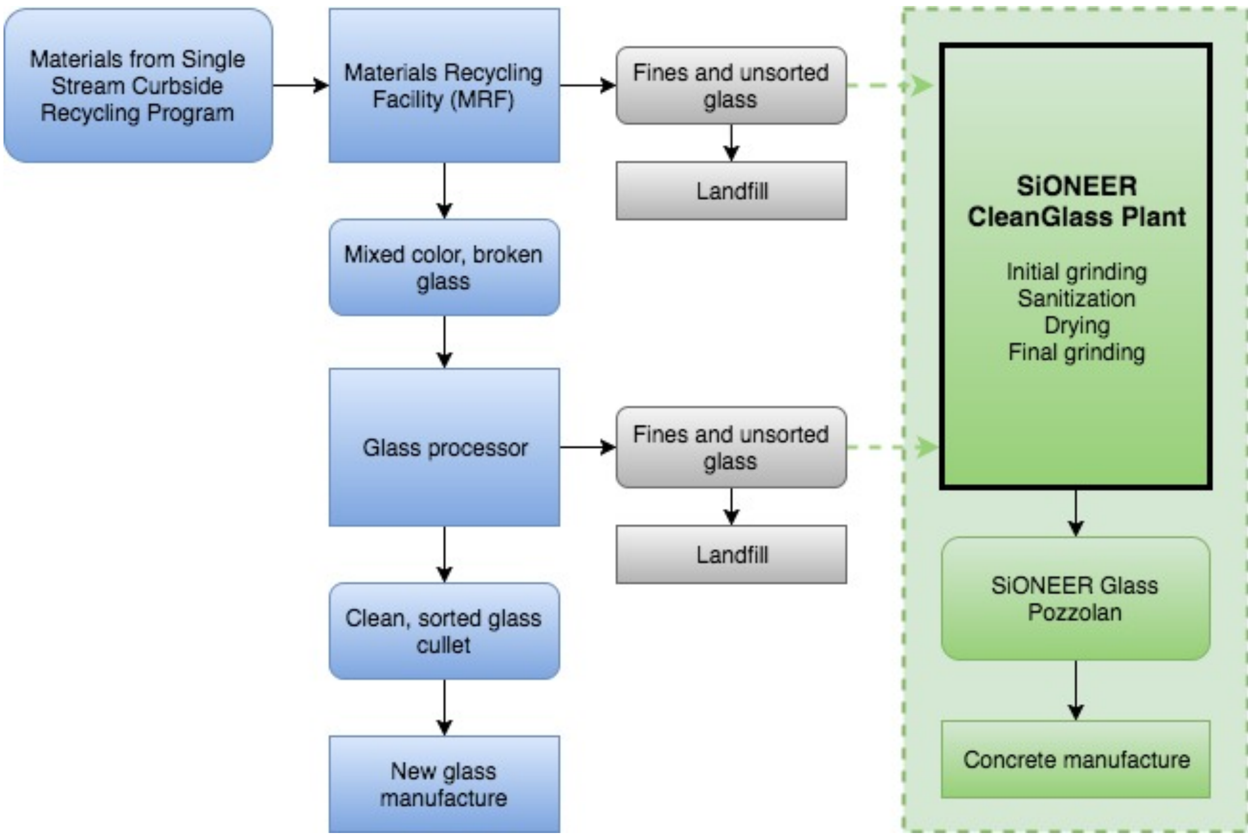

Figure 1. A flowchart depicting where the SiONEER process fits into the current glass recycling and disposal plan and the processing involved in creating the SiONEER glass pozzolan. The blue boxes represent the current glass-recycling loop and the gray boxes represent the flow of waste glasses to the landfill.

Narrative of the SiONEER GHG Emission Reduction Calculation Method

Since the unsorted glass and fines used by SiONEER are not suitable for making new glass and have no other market they can go to, they must be sent to the landfill, meaning a closed loop recycling plan for this glass is not possible. For this reason, the straightforward CARB Greenhouse Gas Reduction Calculator cannot be used (CARB 2016).

In order to calculate the Greenhouse gas emission reductions from the addition of the SiONEER process, a lifecycle approach consistent with the California Air Resources Board's (CARB) Method for Estimating GHG Emissions Reductions from Recycling guide (CARB 2011) was used in conjunction with the Environmental Protection Agency's (EPA) Waste Reduction Model (WARM) Version 13 (March 2015) (EPA 2015). CalRecycle has previously approved this methodology via e-mail correspondence with SiONEER CTO, Cynthia Andela on May 10, 2017.

Since the SiONEER Glass Pozzolan will eventually take the place of a percentage of portland cement in concrete, both the GHG emissions for the SiONEER glass pozzolan and portland cement must be calculated and compared, as shown in Equation 1. This is in line with the methodology used under the WARM model. Definitions of the variables in Equation 1 are provided in Table 1.

$$GHG_{net} = GHG_{PC} - \ GHG_{SPG} \qquad \text{(Equation 1)}$$

Table 1. Definition of variables in the calculation of GHG_{net}.

Variable	Definition	Units
GHG_{net}	the net difference in greenhouse gas emissions between the production of SiONEER Glass Pozzolan and portland cement	tons of CO_2/ton produced
GHG_{PC}	the total greenhouse gas emissions from the production of one ton of portland cement made from virgin materials	tons of CO_2/ton produced
GHG_{SGP}	the total greenhouse gas emissions from the production of one ton of SiONEER Glass Pozzolan (SGP)	tons of CO_2/ton produced

The concept of comparing the SiONEER Glass Pozzolan and portland cement is further illustrated in Figure 2; where the green boxes on the left illustrate the process steps that will be considered when calculating GHG_{SGP} and the maroon boxes on the right illustrate the process steps that will be considered when calculating GHG_{PC}.

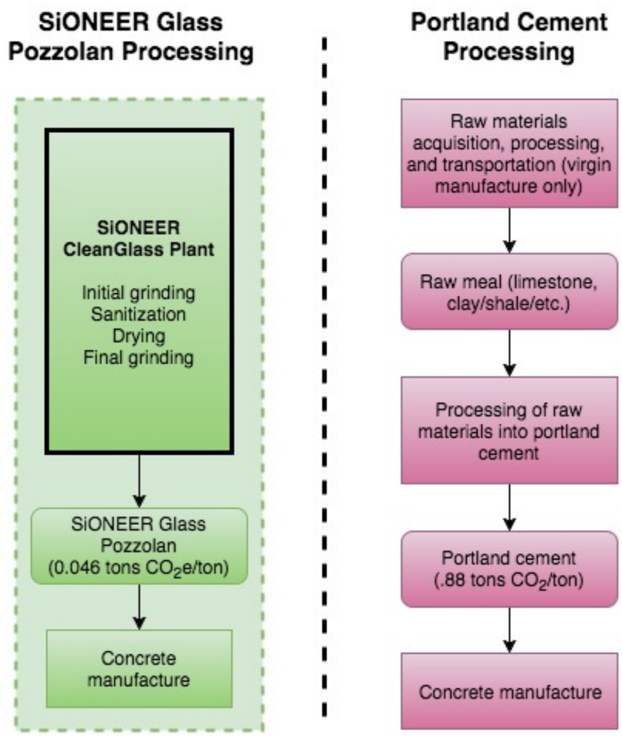

Figure 2. A side-by-side comparison of the processes that will be included in the GHG emission calculation for the SiONEER Glass Pozzolan and portland cement.

Calculation of GHG_{PC}

A brief overview of the production of portland cement (PC) is provided to help understand where the GHG emissions come from. The production of portland cement begins with the mining of raw materials, typically limestone, clay, and shale. These materials are transported to a processing facility where they are ground down to fine powders and analyzed for composition. The materials, at this point called raw meal, are blended based on composition and sent to a cement kiln. In some cases the raw meal is preheated in a precalciner or a flash furnace, other times it just goes directly to the kiln. The internal temperature of a cement kiln is approximately 2000°C. The cement kiln is cylindrical in shape, elevated at a slight angle on one end, with an internal flame at the other end. The raw meal is moved slowly through the kiln through subtle rotation, and as the temperature increases a series of chemical reactions occur. Once the materials reach a temperature of 1450°C, they are rapidly cooled. The cooled material, now in the form of a nodule called clinker, is then interground with calcium sulfate dihydrate, or gypsum, and the resulting product is portland cement (Taylor 1997, Kosmatka and Wilson 2011).

Within the EPA WARM for FLY ASH, a calculation for the GHG emissions of portland cement was included. The following is a summary and explanation of these calculations based on the referenced document.

There are three main types of carbon emissions associated with the production of portland cement: process energy GHG emissions, non-process energy GHG emissions, and transportation energy emissions. The total GHG emissions can be calculated as the sum of these three sources, as shown in Equation 2. The variables are defined in Table 2.

$$GHG_{PC} = GHG_{PE} + GHG_{NPE} + GHG_{TE} \quad \text{(Equation 2)}$$

Table 2. Definition of variables used in the calculation of GHG_{PC}.

Variable	Definition	Units
GHG_{PE}	Process energy GHG emissions	tons of CO_2/ton of portland cement produced
GHG_{NPE}	Non-process energy GHG emissions	tons of CO_2/ton of portland cement produced
GHG_{TE}	Transportation energy emissions	tons of CO_2/ton of portland cement produced

Examples of process energy GHG emissions include the burning of fossil fuels to heat the kiln and the emissions associated with grinding the raw meal and clinker. Non-process energy GHG emissions come from a single source. When limestone, or calcium carbonate ($CaCO_3$), which is the primary raw material in portland cement production, is heated past 825°C, a natural calcination reaction occurs, where CO_2 is released, leaving behind lime, or CaO. This reaction is described in Equation 3.

$$CaCO_3 + heat \rightarrow CaO + CO_2 \quad \text{(Equation 3)}$$

Transportation energy emissions are those emissions associated with the transportation of the materials during the portland cement production process (i.e. raw materials from the mine to the processor and then to the kiln). The values for each of these emission types, as reported by the EPA WARM Report for Fly Ash, for portland cement production, are shown in Table 3.

Table 3. A breakdown of the total GHG emissions associated with the production of one ton of portland cement (EPA 2015).

Emission Source	($MTCO_2$/ton)
Process Energy, GHG_{PE}	0.42
Non-process Energy, GHG_{NPE}	0.45
Transportation Energy, GHG_{TE}	0.01
Total	**0.88**

Calculation of GHG_{SGP}

As stated previously, the EPA WARM model has been successfully applied to fly ash, which is a comparable pozzolan to ground glass (EPA 2015). A similar methodology has been followed here to calculate the GHG emissions for SiONEER Glass Pozzolan (SGP). The streamlined life-cycle GHG analysis in WARM starts at the waste generation reference point of fly ash and only considers upstream emissions after that point. In this case, the waste generation reference point is identified as the point at which the fines and unsorted glasses have been collected at the MRF or glass processor and are marked for the landfill. Emissions associated with glass production, collection, and processing up to this point are not considered in these calculations, nor are the emissions associated with transporting the fines and unsorted glasses to the SiONEER CleanGlass Plant, as it is assumed these emissions will cancel out with the emissions that would have occurred if the fines and unsorted glass had been transported to the landfill.

The processes that occur in the SiONEER CleanGlass Plant include an initial grinding process, a sanitization treatment process, a drying process, and a final grind. All of these processes are run on electricity; therefore, the following calculations were used to determine the total energy requirement (in kWh) to produce one ton of SiONEER Glass Pozzolan for each process. The kilowatt-hours were then converted to tons of CO_2e produced using a conversion provided by the EPA. According to the eGRID (Emissions and Resources Integrated Database), the conversion for the WECC (Western Electricity Coordinating Council) in California is $1\ kWh = 0.5705\ lb\ CO_2e$ (US EPA 2017). The formula used to calculate GHG_{SGP} is provided in Equation 4 and the definitions of the variables are shown in Table 4.

$$GHG_{SGP} = GHG_{G1} + GHG_{treat} + GHG_{dry} + GHG_{G2} \qquad \text{(Equation 4)}$$

Table 4. Definition of variables in the calculation of GHG_{SGP}.

Variable	The total CO_2 required:	Units
GHG_{G1}	for initial grinding of one ton of material	lb. of CO_2/ton produced
GHG_{treat}	for sanitization treatment of one ton of material	lb. of CO_2/ton produced
GHG_{dry}	for removing the moisture from one ton of material	lb. of CO_2/ton produced
GHG_{G2}	for final grinding of one ton of material	lb. of CO_2/ton produced

Calculation of GHG_{G1}

To calculate GHG_{G1} (initial grinding) the following assumptions and calculations were used:

- Power demand of the electric grinding equipment is estimated to be 4 hp-hr/ton.
- This converts to 2.98 kWh/ton produced, which further converts to 1.70 lb. CO_2e/ton produced. See Equation 5.

$$GHG_{G1} = \left(2.98 \frac{kW*hr}{ton}\right) * 0.5705 \frac{(lb\ CO_2e)}{kW*hr} = 1.70 \frac{(lb\ CO_2e)}{ton} \qquad \text{(Equation 5)}$$

Calculation of GHG_{treat}

To calculate GHG_{treat} (sanitization treatment), Equation 6 was used. The variables are defined in Table 5.

$$GHG_{treat} = GHG_{san} + GHG_{heat} + GHG_{stir} \qquad \text{(Equation 6)}$$

Table 5. Definition of variables in the calculation of GHG_{treat}.

Variable	The total CO_2 required:	Units
GHG_{san}	to produce and transport the required proprietary sanitization material to treat one ton of material*	lb. of CO_2/ton produced
GHG_{heat}	to heat one ton of material and keep it steady state for a predetermined period of time*	lb. of CO_2/ton produced
GHG_{stir}	to stir one ton of material for a predetermined period of time*	lb. of CO_2/ton produced

* Some details were omitted from these calculations because the process is proprietary.

To calculate GHG_{san}, the GHG emissions associated with the manufacture of the sanitizing solution, GHG_{manu}, as well as the emissions from the transportation of the solution to the site, GHG_{trans}, were calculated. See Equation 7.

$$GHG_{san} = GHG_{manu} + GHG_{transp} \qquad \text{(Equation 7)}$$

The following assumptions and calculations were used to calculate GHG_{manu}:

- To treat one ton of ground glass, a conservative estimate of one ton of sanitization solution is needed, or approximately 910 liters.
- To make the sanitization solution, 2 g/liter of sanitization powder is required; this equates to approximately 1.82 kg of sanitization powder per ton.
- According to the US EPA, 0.7455 g CO_2 are emitted for every 1 g of sanitization powder produced (US EPA 2011).
- Therefore, 1357 g CO_2, or 3 lbs. CO_2 are associated with every ton of SPG produced. See Equation 8.

$$GHG_{manu} = \left(\frac{1820\ g\ powder}{ton\ SPG}\right) * 0.7455 \frac{(g\ CO_2)}{g\ powder} * .0022 \frac{g}{lb} = 3 \frac{(lb\ CO_2)}{ton\ SPG} \qquad \text{(Equation 8)}$$

The following assumptions and calculations were used to calculate GHG_{transp}:

- 72,000 tons of SPG will be produced every year.
- If 3 lbs. of sanitization powder are required per ton of SPG, 216,000 lbs. (108 tons) must be transported to the plant in Stockton, CA.
- A producer of the sanitization powder is 66 miles from Stockton (132 miles roundtrip).
- This would require six round trips made by a semi-truck (20 tons/load), or 792 miles.
- On average, freight transport accounts for 1700 g of CO_2 per mile (Mathers, Craft et al. 2014).
- Therefore, 792 miles at 1700 g CO_2 per mile results in 1346.4 kg CO_2 per 72,000 tons of SPG produced. This equates to 2968.3 lb. /72,000 tons, or 0.04 lb. CO_2/ton of SPG. See Equation 9.

$$GHG_{trans} = \frac{(792\ miles) * 1700 \frac{(g\ CO_2e)}{mile}}{72{,}000\ tons\ SPG} = 18.7 \frac{g\ CO_2e}{ton} = 0.04 \frac{lb\ CO_2e}{ton} \qquad \text{(Equation 9)}$$

In summary, GHG_{san} is 3.04 lb CO_2e/ton.

To calculate GHG_{heat}, the following assumptions and calculations were used:

- In the sanitization process, a slurry of glass and water is heated and treated with sanitizing solution.
- The treatment process occurs once a day over a six hour period, 50 weeks out of the year.
- The energy demand for the heating of the slurry is estimated to be 23.3 kWh/ton produced, which further converts to 13.3 lb. CO_2e/ton produced. See Equation 10.

$$GHG_{heat} = 23.3 \frac{kW*hr}{ton} * 0.5705 \frac{(lb\ CO_2e)}{kW*hr} = 13.3 \frac{(lb\ CO_2e)}{ton} \qquad \text{(Equation 10)}$$

To calculate GHG_{stir}, the following assumptions and calculations were used:

- Power demand of the electric stirring equipment is estimated to be 50 hp-hr/ton.
- This converts to 1.68 kWh/ton produced, which further converts to 0.96 lb. CO_2e/ton produced. See Equation 11.

$$GHG_{stir} = 1.68 \frac{kWh}{ton} * \ 0.5705 \frac{(lb\ CO_2e)}{kW*hr} = .96 \frac{(lb\ CO_2e)}{ton} \qquad \text{(Equation 11)}$$

Therefore, the total GHG_{treat} is 3.04 + 13.3 + 0.96 = 17.3 lb. CO_2e/ton.

Calculation of GHG_{dry}

- Power demand of the drying equipment is estimated to be 130 kWh/ton produced, which further converts to 74.17 lb. CO_2e/ton produced. See Equation 12.

$$GHG_{dry} = 130 \left(\frac{kW*hr}{ton}\right) * 0.5705 \frac{(lb\ CO_2e)}{kW*hr} = 74.2 \frac{(lb\ CO_2e)}{ton} \qquad \text{(Equation 12)}$$

Calculation of GHG_{G2}

- Power demand of the electric grinding equipment is estimated to be 20 hp-hr/ton.
- This converts to 14.9 kWh/ton produced, which further converts to 8.5 lb. CO_2e/ton produced. See Equation 13.

$$GHG_{G2} = \left(14.9 \frac{kW*hr}{ton}\right) * 0.5705 \frac{(lb\ CO_2e)}{kW*hr} = 8.5 \frac{(lb\ CO_2e)}{ton} \qquad \text{(Equation 13)}$$

These values are aggregated and summed in Table 6. The total GHG emissions associated with the production of one ton of SiONEER Glass Pozzolan is 0.046 metric tons of CO_2e.

Table 6. A breakdown of the total GHG emissions associated with the production of one short ton of SiONEER Glass Pozzolan. A unit of (MTCO_2e/ton) was used in order to compare directly with the GHG emissions associated with production of portland cement.

Emission Source	**(lb. CO_2e/ton)**	**(MTCO_2e/ton)**
Initial grinding, GHG_{G1}	1.7	0.00077
Sanitization treatment, GHG_{treat}	17.3	0.00785
Drying, GHG_{dry}	74.2	0.03366
Final grinding, GHG_{G2}	8.5	0.00386
Total	**101.7**	**0.046**

Calculation of GHG_{NET}

As shown previously in Figure 2, both the process for the production of SiONEER Glass Pozzolan and the production of portland cement will likely include a transportation-based GHG emission when the material is transported from the manufacturer to the concrete manufacturer. This transportation emission is not included in these calculations, as it assumed that these emissions would be nearly equal.

Therefore, according to Equation 1, $GHG_{net} = GHG_{PC} - GHG_{SGP}$, the net GHG emission reductions when comparing one metric ton of SiONEER Glass Pozzolan to one ton of portland cement can be calculated to be:

$$GHG_{net} = 0.88 - 0.046 = 0.834$$

Further, based on the projected production of 72,000 tons of SiONEER Glass Pozzolan per year, the net impact will be a GHG emission reduction of 60,048 tons of MTCO$_2$e annually.

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