Life Cycle and Economic Analysis of Expanded Polystyrene Recycling for UCSB

Introduction

On June 22nd, 2015, the University of California published the UC Policy on Sustainable Practices, which pledged a goal to achieve zero waste across all campuses by 2020.[1] For the Santa Barbara campus (UCSB), a 75% diversion rate of waste from landfill had already been achieved by 2012, but reducing the last 25% is particularly challenging as the easiest reductions have already been made.[2] Expanded polystyrene (EPS) is one of the remaining essential packaging materials for office and lab shipments that needs to be cut from the waste stream to achieve the UC zero waste goal. UCSB is home to over 1,200 labs, many of which require the excellent insulation and lightweight properties of EPS in order to protect shipments of materials and equipment to the labs, posing a barrier to replacing EPS with alternatives. This study examines the environmental and economic performance of an EPS recycling program for the UCSB campus to assess whether implementation is financially feasible and environmentally practical.

Background

One of the unique properties of EPS that differentiates it from many other plastic and alternative materials is its extremely low density (~0.112 – 0.046 g/cm^3) due to being composed of ~95% air.[3] This low density is achieved by exposing polystyrene (PS) beads to steam that boils a blowing agent inside of the bead to produce trapped air in the now expanded polystyrene bead. When these beads are molded into shapes, up to 98% of the final product may be composed of air.[4] In addition to being light weight, EPS is moisture resistant, thermally efficient, durable, and cheap, making it a truly outstanding material for packaging.[5]

Along with the many benefits of EPS come environmental impacts as expected with production of any resource-based plastics. The process of generating one kilogram of EPS emits 2.14 kg of CO_2 to the atmosphere. Many other environmental impacts such as acidification and smog are also associated with the production, usage, and disposal of EPS.[6] Additionally, the light weight properties of EPS make it more mobile with wind, which could lead to it entering the environment more readily than other waste streams. Reflecting this, studies have found concentrations of fragmented EPS in the surface waters of lakes, rivers, and the ocean ranging from 12% to 99% of small plastics.[7,8,9]

In order to address the many impacts of EPS production and end of life, one possibility is to utilize an alternative packaging material that serves the same purpose. However, in a life-cycle assessment (LCA) comparison of EPS to corrugated paperboard (CPB) it was found that there were environmental tradeoffs between the two materials with EPS performing slightly better than CPB for contributions to climate change.[10] Additional material comparisons of EPS to other packaging alternatives by the European Manufacturers of Expanded Polystyrene in 2011 found similar results of tradeoffs between EPS and polypropylene or cardboard with inconclusive differences in global warming potential of the three materials.[11] This provides some evidence of the difficulty in pursuing substitution as a viable solution to diverting EPS waste from landfills. Other options, such as mycelium-based packaging or corn starch packing peanuts are compostable alternatives that, although expensive, may provide favorable opportunities for substitution superior to a recycling program.[12,13]

Impact Analysis

One of the primary issues with recycling of EPS is the characteristic that makes it so useful in the first place: a 95-98% air composition. Due its low density, shipping EPS for reuse or recycling in its raw form is inefficient environmentally and economically.[14] One of the solutions to this issue is to use a densifier to compress the EPS to 1/50th its original volume. This can be done either through baling, cold compaction, or thermal densification. In this case study, thermal densification is chosen as the method of compaction as it sterilizes the material while also achieving a greater level of compaction than the other methods.[15] The StyroMelt™ Thermal Compactor TP1000 was chosen as an example compactor for the inputs and outputs of the process for analysis (Figure 1). The amount of EPS that the compactor can handle per hour is 2 m^3/cycle. Each cycle was 1.5 hours long, meaning that the compaction rate is 1.33 m^3/hr. The energy demand of the machine averages 6 kW, leading to the following calculation of the required energy to compact 1 kilogram of EPS (assumed density is 25 kg/ m^3):

$$Energy\ to\ compact\ 1\ kg\ of\ EPS = 6\ kW * \left(\frac{1\ hr}{1.33\ m^3 * 25\frac{kg}{m^3}}\right)$$

$$Energy\ to\ compact\ 1\ kg\ of\ EPS = 0.18\ kWh$$

Figure 1. StyroMelt Thermal Compactor TP1000.[16]

Gabi 6 was used to model the inputs and outputs of the system and the processes involved (Figure 2). The EPS production (1 kilogram reference unit) was provided by the European Manufacturers of Expanded Polystyrene (EUMEPS) and assumed to be shipped 11000 kilometers via ocean freight from China to California and approximately 300 kilometers via diesel truck (18,600 kg capacity) to where it is used here in Santa Barbara. This may not realistically parameterize the transportation of EPS used in Santa Barbara, but, for purposes of comparing landfilling and recycling, the transportation impact in this process is the same. The densification process is defined simply as an input of energy and EPS into an output of densified PS. This does not account for the environmental impact of the materials to make the densifier, but it's assumed that the lifetime operation of the densifier is where the majority of its impact would occur. The densified EPS is then shipped 200 kilometers via diesel truck to a production facility in Los Angeles where it is assumed to displace PS granulate in a 1 to 1 ratio using the avoided burden approach. If the recycled content approach was used instead it would limit the benefits of recycling to removal from the landfill, rendering the process environmentally ineffective. In addition, the displacement of PS granulate is not entirely suitable for the output of the densifier as it does not produce granulate as an output. For the purposes of this LCA, however, it's assumed that the displacement does occur for virgin PS materials.

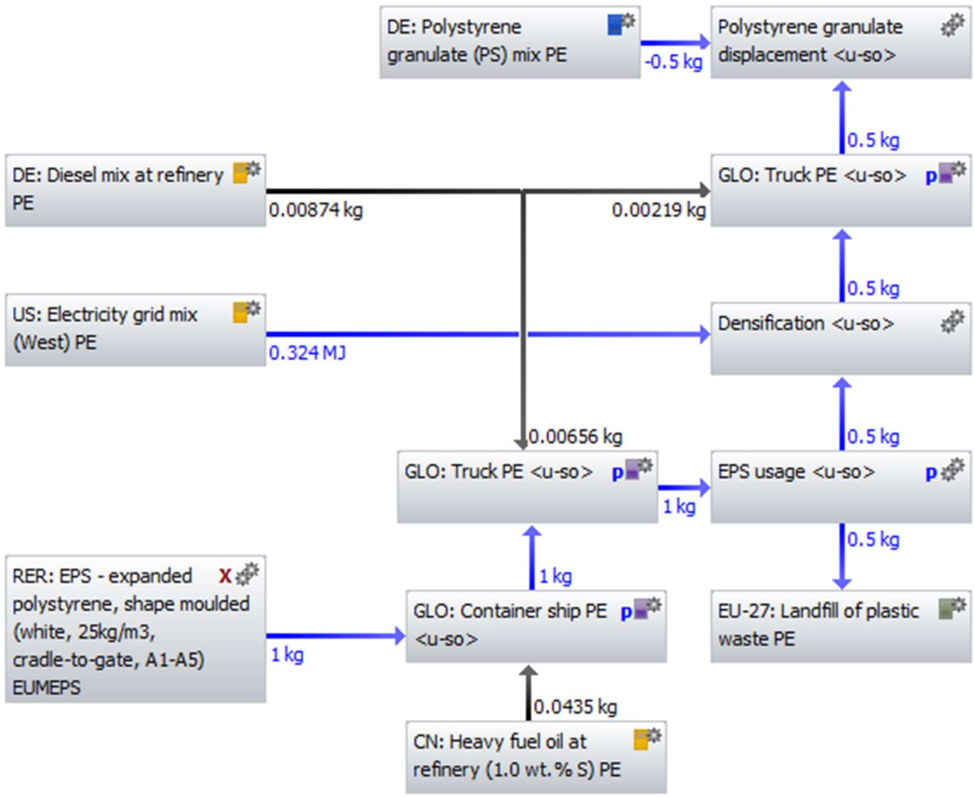

Figure 2. Gabi LCA of EPS with 50% recycling rate.[17]

The impacts of EPS recycling versus landfilling were compared, finding in all Traci 2.1 environmental impact categories that recycling had lower impacts than landfilling the EPS (Table 1). Notable differences in the two options include the reduction in half of global warming potential and in three quarters of fossil fuel resource intensity. These two category changes are as a result of the displaced production process for PS granulate. The energy intensity and fossil-fuel usage of producing the PS granulate outweigh the energy needed to operate the densifier, causing these net positive effects of full recycling. To contextualize the reduction in global warming potential through this process, if the truck was fully loaded with densified EPS (18,600 kg), this would have GHG reductions of 20.6 metric tons of CO_2 equivalent, which translates to 4.3 passenger vehicles driven for one year.[18] Although this is a relatively minor reduction to overall greenhouse gas emissions, it is a large percentage of current emissions from EPS usage and provides progress towards achieving the UC zero waste goal. Paired with an expanded Isla Vista or Goleta community collection of EPS, the program could achieve greater absolute GHG reduction and waste diversion each year.

Table 1. Traci 2.1 impact categories for either landfilling or fully diverting to recycling.[19]

Impact Category	Landfill	Full Recycling	Reduction of Impact Category
Acidification [kg SO2-Equiv.]	0.0148	0.0101	32%
Ecotoxicity [CTUe]	0.1475	-0.1192	181%
Eutrophication [kg N-Equiv.]	0.0007	0.0004	43%
Global Warming Air [kg CO2-Equiv.]	4.2954	2.0779	52%
Human Health Particulate Air [kg PM2,5-Equiv.]	0.0012	0.0005	58%
Resources, Fossil fuels [MJ surplus energy]	14.5403	3.9781	73%
Smog Air [kg O3-Equiv.]	0.2883	0.2101	27%

Economic Analysis

Due to the relatively minor greenhouse gas savings of the EPS recycling program, the cost becomes a particularly important aspect of the program in order for it to achieve successful implementation. For the economic analysis, a case study from UC Davis was used to develop the cost and benefit structure: 11 cents per kilowatt hour, 16 cents per kilogram on site collection cost, $1.26 per kilometer for truck hauling[20], 1.5 cents per kilogram avoided trash collection, and 33 cents per kilogram of densified EPS sold. With 18,600 kilograms of densified EPS transported per trip and 200 kilometers traveled, this comes out to each full trailer's net benefit as:

$$\begin{aligned} Net\ Benefit = 18{,}600\ kg * (&price\ per\ kg\ of\ densified\ EPS \\ &+ avoided\ trash\ collection\ cost\ per\ kg - collection\ cost\ per\ kg \\ &- cost\ per\ kg\ densified\ electricity) \\ &- cost\ of\ transportation\ of\ 18{,}600\ kg\ densified * distance \end{aligned}$$

$$\begin{aligned} Net\ Benefit = 18{,}600\ kg \\ &* \Big(\$0.33\ per\ kg + \$0.015\ per\ kg - \$0.16\ per\ kg - \$0.11\ per\ kWh \\ &* 0.18 \frac{kWh}{kg}\Big) - \$1.26\ per\ km * 200\ km \end{aligned}$$

$$\boldsymbol{Net\ Benefit = \$2820.72\ per\ trip}$$

This estimate is a bit larger per kilogram than that of the UC Davis program. At 400 cubic yards per load and a density of 10 kg per cubic meter (loosely packed), the amount of recycled EPS in 5 loads was 26,159 kg of EPS, which they received $3,000 in savings for. This could be partly be explained by the fact that UC Davis did not compact their EPS on site since shipping for each load was $150 whereas the onetime shipping of EPS was $252. The net benefit here is likely an optimistic estimate as the amount of labor required to coordinate and operate the program would be quite high. In order to compact 18,600 kg of EPS alone, it would take approximately 558 hours of operation time or about 2 cycles (1.5 hours) per day of UCSB being in session. If it's assumed that this would require the same wage as collection, the result is a net loss of $155.28 per load. Costs such as the original purchase of the compactor or others not readily apparent may also mount up, making this project a riskier financial investment for UCSB.

Social Opportunity and Challenges

One of the particularly challenging aspects of starting and maintaining an EPS recycling program would be buy-in from the school and students. UCSB provides a prime opportunity to start an EPS recycling program as it has an engaged student body along with a possible success story (UC Davis) as a model to build its own program. In addition, the EPS recycling program could be expanded to service the surrounding community to maintain enough supply for the program to continue running and, based on other cases, potentially result in a shorter payback period.[21] One issue with this, however, is the looming potential for bans of EPS in Santa Barbara County. Recyclers such as those in the Institute of Scrap Recycling Industries have come out against bans of products as it proves harmful to their businesses when supply is suddenly cut short.[22] In the case of UCSB, the campus has already banned EPS in food packaging, which could encourage initiatives to expand the ban to other forms of EPS, potentially even by local government. Although this would achieve the desired result, it may cut the program short before it is able to pay itself back or decrease overall environmental impact.

Limitations

One of the primary limitations of the study is the assumption that the densified EPS displaces polystyrene in a 1 to 1 ratio. Economically, the compressed PS may be purchased at a much lower price than usually paid for PS or used in goods that would have otherwise not been produced and consumed. This would lower the actual ratio of PS displacement by the densified EPS. Environmentally, the polystyrene granulates may be higher grade than the densified EPS, meaning that the displacement benefits would be higher than actual as more processing would be needed in order to turn the densified EPS into PS granulates. The numbers for EPS are also provided for by the EUMEPS, which may result in some downward bias in the estimation of environmental impacts.

The financial efficacy of the EPS recycling project is of particular importance to its success, meaning that any uncertainty with the costs and benefits of the program are of concern. One such problem is that the agency in Los Angeles working with UC Davis to purchase their EPS (NEPCO) would lower the price that it pays for the densified EPS or stop accepting it altogether. Further research on alternative buyers of densified EPS would provide a better sense of guaranteed income streams from selling densified EPS.

Another key assumption of this analysis is that enough EPS will be generated by the campus to fill the trailer with 18,600 kg of densified EPS throughout the year. This would be the equivalent to each of the 1,200 labs in UCSB producing ~6 large boards of EPS 1 meter long, 0.5 meters wide, and 0.2 meters thick each year. The only evidence that this may be feasible is that UC Davis collects more than that in EPS each year, but their medical school is one of the primary drivers of that supply.

Conclusion

An EPS recycling program provides UCSB with an opportunity to take another step towards the UC goals of zero waste by 2020. However, due to the difficulties in recycling EPS, the program may be financially inefficient while achieving only minimal environmental benefits. The EPS recycling process would have to be streamlined and run with the help of volunteers in order to maintain a positive return that keeps the program sustainable. By accessing an engaged student body and maintaining consistent transactions of densified EPS, the program could achieve stability that sees it successfully divert the EPS waste while also generating money for the university or for student groups. One shortcoming of the EPS recycling program is that it does not truly avoid the resource demand and impact of the manufacturing of EPS in the first place. Although it provides an interim solution to the issue of how irreplaceable EPS is, alternative materials should be pursued as the long-term replacement for EPS to avoid impacts with production and recycling processes.

Cost-benefit analyses of alternative packaging materials such as the mycelium-based inserts or corn starch peanuts would provide a better look at what options are available to avoid

EPS entirely. Unfortunately bans on EPS packaging would likely result in alternatives such as cardboard inserts or other materials with similar environmental impacts to EPS. Instead, programs and policies that encourage suppliers to switch to alternative materials such as economic incentives for the mycelium-based packaging inserts could bring about the desired switch. Although this may begin as an expensive alternative to EPS, it could be considered an investment in the competitiveness of the alternative. As it receives more money and the business expands, it allows for scaled production, lowering the price that UCSB pays. The UC system as a whole has a strong capacity to change the actions of its suppliers, encouraging the adoption of aggressive investment in alternatives to EPS. Doing so may provide an example for other institutions to follow suit, pressuring the industry as whole to change.

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[1] University of California, Energy and Sustainability. (2015, June 22). Retrieved May 28, 2016, from http://policy.ucop.edu/doc/3100155/SustainablePractices

[2] Waste Actions. *UCSB Sustainability.* Retrieved May 28, 2016, from http://www.sustainability.ucsb.edu/waste-actions/

[3] What is Expanded Polystyrene (EPS) foam? *Insulation Corporation of America.* Retrieved May 28, 2016, from http://insulationcorp.com/eps/

[4] Polystyrene. United States, Environmental Protection Agency. (1995, January). Retrieved May 28, 2016, from https://www3.epa.gov/ttnchie1/ap42/ch06/final/c06s06-3.pdf

[5] Expanded polystyrene (EPS). Retrieved May 28, 2016, from http://www.plasticseurope.org/what-is-plastic/types-of-plastics-11148/expanded-polystyrene.aspx

[6] Expanded Polystyrene Data. Retrieved May 19, 2016, from http://www.plasticseurope.org/

[7] Faure, F., Demars, C., Wieser, O., Kunz, M., & Alencastro, L. F. (2015). Plastic pollution in Swiss surface waters: Nature and concentrations, interaction with pollutants. *Environ. Chem. Environmental Chemistry, 12*(5), 582. doi:10.1071/en14218

[8] Mani, T., Hauk, A., Walter, U., & Burkhardt-Holm, P. (2015). Microplastics profile along the Rhine River. *Sci. Rep. Scientific Reports, 5*, 17988. doi:10.1038/srep17988

[9] Kang, J., Kwon, O. Y., Lee, K., Song, Y. K., & Shim, W. J. (2015). Marine neustonic microplastics around the southeastern coast of Korea. *Marine Pollution Bulletin,96*(1-2), 304-312. doi:10.1016/j.marpolbul.2015.04.054

[10] Tan, R. B., & Khoo, H. H. (2005). Life cycle assessment of EPS and CPB inserts: Design considerations and end of life scenarios. *Journal of Environmental Management, 74*(3), 195-205. doi:10.1016/j.jenvman.2004.09.003

[11] Life Cycle Assessment of the Industrial Use of Expanded Polystyrene Packaging in Europe *PricewaterhouseCoopers.* Retrieved May 29, 2016, from http://www.fishboxes.info/wp-content/uploads/2012/04/EUMEPS_report_PwC_112211.pdf

[12] Mushroom Packaging. Retrieved May 29, 2016, from http://www.ecovativedesign.com/mushroom-packaging

[13] Pros and Cons of Biodegradable Packing Peanuts. Retrieved May 29, 2016, from http://www.hpcorporategroup.com/pros-and-cons-of-biodegradable-packing-peanuts.html

[14] Tullo, A. H. (2015, March 23). Fuming Over Foam. *Chemical & Engineering News*. *93*(12), 23-25. Retrieved May 29, 2016, from http://cen.acs.org/articles/93/i12/Fuming-Over-Foam.html

[15] Rubio, M. R. (2016, April 19). Trends in Recycling of EPS Foam | EcoMENA. Retrieved May 30, 2016, from http://www.ecomena.org/recycling-eps-foam/

[16] StyroMelt. Retrieved May 28, 2016, from http://www.recycle-styrofoam.com/products/styromelt/

[17] Life Cycle Assessment LCA Software: GaBi Software. Retrieved May 27, 2016, from http://www.gabi-software.com/

[18] Greenhouse Gas Equivalencies Calculator. United States. Environmental Protection Agency. Retrieved May 30, 2016, from https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[19] Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI). United States. Environmental Protection Agency. Retrieved May 29, 2016, from https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci

[20] West Regional Reefer Rates. Retrieved May 30, 2016, from http://www.dat.com/resources/trendlines/reefer/west-regional-rates

[21] DENSIFICATION AND RECYCLING OF POST CONSUMER POLYSTYRENE (PS #6) PACKAGING IN ONTARIO MUNICIPALITIES *Waste Diversion Ontario's Continuous Improvement Fund.* Retrieved May 29, 2016, from http://cif.wdo.ca/pdf/reports/130/130_report.pdf

[22] Carpenter, M. (2013, August 5). ISRI Issues Policy on Bans and Fees for Recyclable Paper and Plastic Bags. Retrieved May 30, 2016, from http://www.isri.org/news-publications/article/2013/08/05/isri-issues-policy-on-bans-and-fees-for-recyclable-paper-and-plastic-bags#.V0zYTbgrJaQ