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LETTING THE LIGHT IN: AN INVESTIGATIVE REPORT ON THE EXTERNALITIES OF PVC WINDOWS

Final project
by
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Introduction

In the field of window frames, windows made out of Polyvinyl chloride (also known as PVC) have become a viable market alternative to the more traditional models made out of wood or aluminum. There are a number of reasons why consumers are increasingly choosing these models over their viable counterparts. First, when factoring in costs of maintenance and upkeep, PVC windows are 20% less costly and last ten years longer on average than wood windows (Kandelaars et. al, 1997, p. 14). Secondly, vinyl windows do not require repainting and are thus a lower maintenance model than wood and aluminum. Unfortunately, despite the market incentives to purchasing vinyl windows, customers are often unaware of the negative externalities that pervade the lifecycle of PVC-based products. As PVC is a carcinogen in its gaseous form (known as VCM), producing and manufacturing vinyl windows has a long history of negative health and environmental effects. Although in many places adequate recycling infrastructure exists for PVC- a substance that is 100% recyclable- the PVC industry is beleaguered by cases of improperly disposed products. In incurring these negative externalities, PVC window frames are no exception.

In this paper we will analyze the life cycle of the PVC window. Specifically we will discuss the production of polyvinyl chloride, the manufacturing and distribution of vinyl windows, and their ultimate disposal throughout New England via Oxy Vynils Canada Manufacturing Plant, Harvey Manufacturing Plant, and Boston Building Resources (BBR). Due to a number of negative implications often associated with window frames made of PVC, we will also investigate a number of detriments involved in this process. In order to confirm that all actors in this process maintain best practices involved in the lifecycle of the windows, we have investigated the practices in each plant and company. From a public health standpoint, vinyl
chloride- a gas used to manufacture polyvinyl chloride- is a known carcinogen that can be dangerous to the health of workers in PVC manufacturing plants (EPA, 2006). From an environmental standpoint, there are a slew of problems surrounding PVC production and disposal. Historically, vinyl chloride has been found in groundwater, surface water and soil profiles near PVC production sites (EPA, 2006). However, the EPA notes that these pollution problems can be greatly minimized if production plants take the necessary safeguards (EPA, 2006), and the degree to which this safeguards have been embodied comprises a substantial focus of our research. Lastly, non-recycled PVC frames often end up in landfills or are incinerated, which can produce a harmful toxin called dioxin (Shibamoto et al., 2007). Based on the environmental harms created by improper disposal, we have also investigated the recycling practices of involved companies.

PVC has a wide variety of uses and is a versatile and durable material. If its recycling capacity can be optimized, the environmental issues associated with PVC’s production could be partially offset. We intend to investigate whether or not Oxy Vinyls Canada, Harvey, and BBR have taken the necessary precautions to prevent against the negative effects of vinyl chloride pollution and improper PVC disposal through taking necessary safeguards during production and through recycling unused PVC. A large number of vinyl windows that were installed in the 1980’s are at the end of or nearing the end of their life and are ready for removal and recycling, meaning that proper post-consumer recycling is incredibly important in reducing these negative externalities as well (G. Caplan, personal communication, Feb 12, 2015). The ultimate aim of our research is to discover the origin of the material used and understand the “footprint,” or health and environmental effects of PVC windows in a broad sense by looking at PVC production, window construction, and breakdown. Finally, we will also examine the durability
and efficiency of the windows in the home through a short homeowner survey, and hope to investigate whether the windows are being recycled, who they are being recycled by, and to what degree recycled content is being utilized in the production of new windows.

BACKGROUND

Lifecycle of Polyvinyl Chloride

PVC is by market share the third largest thermoplastic in the world with approximately 36 million tons produced in 2011 (Stichnothe and Azapagic, 2012). There are various steps in the lifecycle of a PVC window frame that need to be considered when assessing the economic and environmental effects of these products (Figure 1).

Figure 1. Diagram of the lifecycle of PVC from production to disposal, including the transport of material (Created by Gracie Villa using the program, Inspiration).
The chemical gas vinyl chloride (VCM) is used to manufacture PVC. This gas is created through a chemical reaction where ethylene (a hydrocarbon widely used in the chemical industry) reacts with chlorine. The resulting VCM is pressurized and liquefied in a polymerization reactor, where it is agitated at high speed to produce PVC in slurry form that is later dehydrated and hardened (PVC.org). It is during this conversion process that many of the human health detriments and pollutant externalities surrounding PVC production are produced.

Vinyl chloride is a known human carcinogen (cancer-causing agent) and is also a known genotoxicant, causing chemical alterations of DNA in tissues that may lead to cancer following exposure of humans and experimental animals (U.S. EPA, Toxicity and Exposure Assessment for Children’s Health). The primary target organ for vinyl chloride exposure is the liver, and several studies in experimental animal models have demonstrated that early life exposure to vinyl chloride can increase susceptibility to cancer later in life. Other non-cancer adverse effects on the liver, immune system, skin, central nervous system, lung and kidneys have also been reported (U.S. EPA, Toxicity and Exposure). Based on this data, the U.S. Agency for Toxic Substances and Diseases Registry has characterized fetuses, infants, and young children as a “highly susceptible population” to vinyl chloride exposure (U.S. EPA, Toxicity and Exposure). However, according to PVCs Europe (the main global advocacy group for PVC), exposure to the toxic gas today is greatly limited to employees at PVC manufacturing plants, and outside exposure is incredibly rare (PVC.org). Despite PVCs Europe’s assurance, the EPA does not seem convinced. In a 2007 Toxicity and Exposure Report, the EPA notes that the environmental detriments surrounding PVC production include emissions created during production or incineration, which can contaminate groundwater and drinking water when collected in clouds.
and precipitated (U.S. EPA, Toxicity and Exposure). VCM is also considered one of the 188 hazardous air pollutants and is listed under CERCLA as part of the Priority List of Hazardous Substances (source), making its release a major concern for the neighborhoods surrounding the plants producing this material.

After PVC is manufactured, it is sent to various plants that will use it for various purposes, including the assembly of PVC window frames. The global annual consumption of PVC for window frames is estimated at around 3 million tons, or around 8% of the global PVC production (Stichnothe and Azapagic, 2013). During the production of these frames, rejects from manufacturing, or post-industrial waste, can either be disposed or recycled and reused to make more frames. This recycling process has on average 85 times lower impacts than the virgin PVC resin, with the greatest reductions achieved for eco-toxicity (Stichnothe and Azapagic, 2013).

Once completed, the PVC window frames will make their way to various distribution companies and will then be sold to homeowners, who will make use of them for 10 to 20 years, depending on the amount of natural weathering that they undergo. After the windows reach the end of their lives in the home, they are either disposed in landfills or recycled for use again in other PVC products. Because there is such a large volume of PVC in the window frames available for recycling, their proper disposal could potentially lead to a significant reduction in environmental impacts of PVC window frames (Stichnothe and Azapagic, 2013). If frames are properly disposed of, the recycling process proceeds as follows. Frames are taken to recycling facilities and are crushed using hammer mills to break up the frames and liberate aluminum and ferrous metals contained within; the metals are separated and sent for separate recycling (Stichnothe and Azapagic, 2013). The waste is then sorted manually into white and non-white PVC. The white chips can be recycled for new frames multiple times, and the non-white can be
used for non-visible parts of the frame (Stichnothe and Azapagic, 2013). PVC can also be recycled chemically by melting or dissolving scraps. Some processes use the dissolution of PVC in organic solvents like cyclohexanone, ethyl methyl ketone or tetrahydrofuran (Braun, 2002). By selected extraction of PVC from the resulting plastic waste, uncontaminated PVC for further application can be obtained.

While this method of recycling is effective and efficient at transforming post-consumer PVC into usable material, the characterization of the material being recycled is also incredibly important. An analysis of the composition and a detailed knowledge of the heat history and the molecular weight of a PVC scrap are useful before reprocessing in order to reduce toxic fumes emitted and thereby reduce air pollution, health hazards, and other negative environmental effects (Braun, 2002). With the proper characterization, more PVC could be salvaged from post-consumer waste. In addition, significant savings of environmental impacts can be achieved by using PVC from recycled waste frames (post-consumer) as compared to virgin PVC resin, similar to the savings received from recycling post-industrial PVC waste (Stichnothe and Azapagic, 2013). For the post-consumer waste, if the system is not credited for the recycled metals, the reduction in the impacts is on average 34 times, and the greatest savings are again for eco-toxicity (Stichnothe and Azapagic, 2013). If PVC is not recycled, it is sent to a landfill or incinerated. Incineration results in the emissions of toxins like dioxin, and slow degradation of PVC in a landfill also emits this toxin (Shibamoto et al., 2007).

**Wood and PVC Window Frames**

As home renovation projects continue to adapt to new innovations, builders and contractors are constantly in search of the right products to meet their clients’ demands. While wood has long been the standard for window construction, new advances in PVC offer builders
more options and increased durability, with benefits that often outweigh any advantages wood might offer.

Perhaps the number one advantage to PVC is its longevity. Whereas wood is susceptible to environmental conditions and severe weather, PVC does not rot, corrode, delaminate or swell excessively from moisture, and is impervious to damage from insects. PVC simply does not absorb moisture, leading to minimal maintenance needs (Andrade, 2011). Additionally, PVC products are also incredibly durable, resisting even the toughest of weather events. Whether faced with extremes such as rain, hail, sun, heavy snow, sleet or humidity, year after year architectural structures that utilize PVC products have had relatively minimal problems despite heavy weather-based abuse (Andrade, 2011). It is this strength in material that has led PVC products to grow in popularity in New England, despite the increasingly tough seasonality. However, once damaged, it is incredibly difficult and costly to fix PVC windows, so they are often replaced rather than repaired. Wood is versatile and cheap material, so damage can more easily be repaired.

While the longevity and durability offered by PVC products make them more attractive than wood products, it is the adaptability of the material that argues for their level of accessibility for builders and contractors. PVC products are applicable to virtually any type of house or structure, no matter what the style. And in addition to a full line of standard products, re-manufacturers of PVC have the capacity to custom-create anything that can be done in wood through upgraded technologies that make use of CAD/computer-generated drawings (Andrade, 2011).

One disadvantage to PVC is its high initial investment in comparison to wood. PVC is almost twice as expensive as wood. However, the return on investment of PVC is often quickly
evident. If the house had used wood products, the savings achieved by using wood would be lost the first time the owner needs to repaint (which is usually about three or four years after the initial paint, and sooner if the home is located near saltwater (Andrade, 2011). Vinyl windows do not need to be repainted. Additionally, wood is much more susceptible to wood and breakage than Vinyl windows, which do not rot and are fairly resistant to breaking. However, vinyl windows are not totally insulated from ascetic damage. In some cases, climate can significantly influence the appearance of the vinyl window. Furthermore, dirt can penetrate the pores of the vinyl material, and cannot be removed even with the most efficient cleaning agents (Kalesi, 2009).

While both vinyl and wood windows are manufactured to ensure high levels of energy efficiency, wood is still the most sustainable choice of window material. Taking a variety of environmental impacts into consideration, studies have shown that wood is a “greener” choice that PVC. Most significantly, PVC windows emit, on average, 160 kilograms more Carbon Dioxide than wood due to emissions produced during production and transportation (Wood Window Alliance). Additionally, wood windows do not have nearly the same environmental justice implications as PVC because their manufacturing does not emit any carcinogens or pose any risk for dangerous chemical spills, like PVC does. Despite the environmental concerns associated with PVC windows, consumers and builders prefer vinyl because of the superior durability, longevity, and adaptability.
METHODS

We conducted our investigation on the health effects, environmental effects, and recycling infrastructure of vinyl windows using three research tools: personal interviews, a homeowner survey, and online review of scientific literature. Along each step of the PVC life cycle (Figure 1), we looked at the specific practices of: Oxy Vinyls Canada Manufacturing Plant, Harvey Building Products Manufacturing Plant, Boston Building Resources (BBR), various homeowners, and the James G. Grant Disposal Company. The information obtained from each company comprised our results on the sustainability of vinyl windows.

We first conducted research on the practices of Oxy Vinyls Canada by looking through their website and looking for case studies of angiosarcoma and other PVC-related health issues of people in the area. We also collected information on PVC production from global PVC advocacy group PVCs Europe and contacted Arjen Sevenster, the Manager of Technical and Environmental Affairs of the European Council of Vinyl Manufacturers, to inquire about PVCs Europe’s role in PVC production and research, along with reported cases of PVC-related health effects. PVCs Europe claims that, “Other than its flammability potential at release, once in the open atmosphere VCM quickly dissipates posing little threat to human health in such a diluted form when exposed to normal daylight”. Considering the long history of VCM pollution in the atmosphere, we seriously questioned the validity of this statement.

Next, we traveled to Manchester, NH for a tour of the Harvey Manufacturing Plant in Manchester, NH, where we conducted personal interviews in order to obtain information on the PVC window manufacturing process. The managerial staff- headed by site manager Tim Swisher- provided an in depth tour of the facility, which focused on the origin of wood and vinyl window materials, the construction and testing of vinyl windows, and the recycling of scrap
vinyl and glass. Through questions asked to plant employees and the follow up research we gathered on the Harvey website after the tour, we were able to gain insight into the environmental impact of both the production of vinyl windows and the disposal of those materials that were defective or left-over.

Throughout this study, we were also in contact with Greg Caplan of Boston Building Resources. He provided us with information on BBR’s mission, customer base, process of operation, and steps taken for the recycling and disposal of old vinyl windows.

In order to evaluate the practical value of Harvey’s vinyl windows at the homeowner level, we sent a survey to a number of Harvey customers whose contact information was provided by our advisor, Greg Caplan. To gain further information, we also considered the Yelp.com reviews that were linked to the Harvey website for our research and contacted those reviewers to complete our survey. The survey consisted of ten questions and allowed all participants to remain anonymous (Refer to Appendix 1 for a copy of the survey questions).

In addition to this survey, we used online literature on the lifecycle of vinyl windows, health and environmental effects of PVC, and the recycling of vinyl windows and PVC to support our findings. Specifically, we used the Boston College Library Database and GoogleScholar.com to find relevant journal articles that pertained to our topic. While our interview and survey responses helped determine the recycling practices of Harvey Building Products and homeowners, window preference, and vinyl window construction at Harvey, the literature review gave us a broader assessment of vinyl windows that we were then able to apply to our results. We also researched community opposition to PVC manufacturing plants and searched for potential complaints towards the Oxy Vinals Canada plant to gauge the specific health and environmental impact concerns surrounding PVC manufacturing.
RESULTS

PVC Production: Oxy Vinlys Canada

The analysis of PVC production at Oxy Vinlys Canada Manufacturing Plant showed that although the potential health effects due to VCM pollution can be disastrous, Oxy Vinlys’ Canada has been extremely lucky in that it has not had any recorded incidents of damage to human health through their manufacturing practices. Since the plant’s construction in 1957, there have been no public complaints of PVC contamination (source). It is much more difficult to track cases of employee illness due to PVC exposure, however it is worth noting that The Vinyl Institute awarded Oxy Vinyl’s Canada their top safety and environmental stewardship award for going six consecutive years with no recorded accidents. Additionally, since the PVC industry underwent a vast overhaul in the 1980’s, incidents of occupational illness have become much less frequent. According to figures from the Occupational Safety and Health Administration (OSHA), the industry’s occupational injury and illness rate has improved by 82% during the past 21 years (PRNews.com, 2014). Although the ramifications of vinyl chloride exposure can be disastrous, the industry appears to be aggressively pursuing their commitment to protecting the health and wellbeing of their workers.

From an environmental standpoint, Oxy Vinlys Canada has been diligent and successful at keeping their emissions at levels well below those that would cause harm to the environment or to human health. According to a 2014 emissions report by the Niagara Community Awareness Response group, greenhouse gases per kilogram of product produced at the plant has gone down 19% from 2012. Combustion emissions, which are directly tied to production rates, have sunk by 3% from 2012 despite an 18% increase in production from 2012 (Niagara Community Awareness and Emergency Response Group, p. 14, 2014). These substantial emissions
reductions are due to structural and procedural improvements at the plant due to a 2008 ruling by the Ontario Environmental Protection Agency that allowed the plant special standing as an emitter. The rule loosened the emissions standards for Oxy Vinlys Canada from 1 microgram of PVC emissions per cubic meter to 49 micrograms of PVC emissions per cubic meter provided that the plant make a number of improvements to lessen their emissions (Larocque, 2008). With the release of this 2004 emissions data, it appears that Oxy Vinlys Canada is well on its way to making good on its promise of emissions reduction.

The global PVC industry is largely unwilling to admit the potential harm to be caused by PVC production-side emissions. Arjen Sevenster replied to our email, “VCM degenerates in the sunlight in a few days and poses no threat to wider human health” (A. Sevenster, personal communication, Apr 14, 2015). When we followed up with him citing studies in India and New Orleans, Louisiana where VCM emissions had concentrated in the atmosphere and precipitated sown, polluting surface water, he declined to comment. Obviously, there is a large discrepancy in the public information provided on PVC pollution that is highly source-dependent.

**Manufacturing of PVC Window Frames: Harvey Building Products**

Harvey Building Products is the leading manufacturer and distributor of high quality building products in the New England area, and their extensive line of PVC window frames is core to their business model. We investigated the Manchester, New Hampshire plant as part of the lifecycle of the windows sold by BBR in order to determine how recycling capacities were being utilized and waste being produced. On the tour of the Harvey Plant, we discovered that Harvey recycles post-industrial PVC waste by the processes outlined in the literature review (Stichnothe and Azapagic, 2013). Harvey recycles the pre-consumer waste using the same methods and processes as post-industrial waste is typically recycled. Afterwards, the recycled
PVC is sorted manually into white and non-white PVC chips, which can both be recycled for new frames. The white chips are used as the outer ascetic covering for the window frames whereas the non-white PVC chips make up the structural component of the windows- known as extrusions. Again, this type of recycling has, on average, 85 times lower impacts than the virgin PVC resin, with the greatest reductions achieved for eco-toxicity. At the Harvey plant, the post-industrial PVC waste, collected as scraps, is sent back to Oxy Vinyl Canada in order for the PVC to be repurposed (T. Swisher, personal communication, Apr 20, 2015).

Unfortunately, although Harvey is committed to adhering to the top industry standard in their recycling practices, the mindset of sustainability is not pervasive throughout the entire manufacturing process. In order to stress test their windows, an amount of water equivalent of 8 inches of rain over a period of 20 minutes is blasted against the panes of a window randomly chosen from each batch of windows produced (T. Swisher, personal communication, Feb 13, 2015). The water used in the stress test flows directly from the main water system and is drinking quality. Despite this massive amount of drinking quality water used in the process, there is no water reuse system in place at the facility. Although Harvey claims that they are committed to “environmental stewardship”, this practice appears to be in direct contradiction of this commitment. According to T. Swisher (production manager at Harvey’s Manchester, New Hampshire facility) this amount of water used is markedly less than similar plants of comparable size to Harvey (T. Swisher, personal communication, Feb 13, 2015). Nonetheless, by not having a comprehensive water reuse system, Harvey is missing a huge opportunity to affirm their commitment to environmental stewardship.

Despite the water waste produced in the stress testing protest, Harvey has demonstrated their commitment to environmental stewardship in a number of different areas. First off, Harvey
Building Products is an Energy Star partner, helping protect the environment through energy efficient products and practices. Secondly, in packaging their products, Harvey is committed to using 100% recycled materials. Additionally, Harvey minimizes their production-side waste by utilizing computerized optimization systems in cutting vinyl and glass. According to the Harvey Building Products website, utilization of these systems has led to an 85% reduction in vinyl and glass scrap. Harvey has also taken steps to ensure the efficiency of their buildings. Harvey is a member of The United States Green Building Council (USGBC) and have an in-house LEED accredited professional on staff to ensure efficiency (Harvey Building Products, 2015). Although there are definite areas where Harvey can improve their commitment to environmental sustainability, it appears that they are definitely committed to the concept of environmental stewardship.

**Distribution of PVC Windows: Boston Building Resources**

The PVC windows manufactured at the Harvey plant are sold to Boston Building Resources (BBR). BBR is a company that sells and installs doors home improvement items to homeowners. Part of BBR’s mission statement is to “empower homeowners to increase the efficiency and value of their homes.” BBR installs windows and doors for customers based locally in Massachusetts, but the company also utilizes Harvey’s Network to contract installers in the greater New England area in order to utilize a wider client base (G. Caplan, personal communication, Apr 20, 2015). In addition, BBR offers a window removal service where an installer goes to homes, removes PVC windows upon request and sends them to a recycling facility run through Grant Disposal (G. Caplan, personal communication, Apr 20, 2015). As one of the major complaints with vinyl windows is the need for full replacement when they incur
damage, it is integral to optimizing full recycling potential that the windows removed by BBR are recycled.

**Homeowner Perception of Harvey Vinyl Windows**

In order to evaluate the practical value of Harvey’s vinyl windows, we sent a survey to 8 customers who bought Harvey’s PVC windows through Boston Building Resources along with 8 people that had created Yelp reviews on Harvey windows online. Unfortunately, the survey was voluntary, and we were therefore only able to collect five responses during the four weeks that it was open online. This survey showed that four men and one woman participated, all of whom were between the ages of 35 and 74, and that the responses were from the following neighborhoods: Brighton, Jamaica Plain, Greater Boston Area, and Somerville. These and other responses are outlined in Table 1.

**Table 1. Homeowner survey responses**

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age</th>
<th>Neighborhood</th>
<th>When Vinyl Windows Installed</th>
<th>What Happened w/ Replaced Windows</th>
<th>Prefer Wood or Vinyl? Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>35-44</td>
<td>Somerville</td>
<td>&lt; 5 years ago</td>
<td>Landfill</td>
<td>Wood</td>
</tr>
<tr>
<td>Male</td>
<td>55-64</td>
<td>Brighton</td>
<td>&lt; 10 years ago</td>
<td>N/A</td>
<td>Vinyl- more durable</td>
</tr>
<tr>
<td>Female</td>
<td>35-44</td>
<td>Jamaica Plain</td>
<td>&lt; 10 years ago</td>
<td>Landfill</td>
<td>Vinyl- well insulated</td>
</tr>
<tr>
<td>Male</td>
<td>45-54</td>
<td>Greater Boston Area</td>
<td>N/A</td>
<td>Installer Removal</td>
<td>Vinyl- well insulated; must be replaced if damaged</td>
</tr>
<tr>
<td>Male</td>
<td>65-74</td>
<td>Jamaica Plain</td>
<td>&lt; 5 years ago</td>
<td>Installer Removal</td>
<td>Vinyl- solid and well-insulated</td>
</tr>
</tbody>
</table>
Out of these five participants, four prefer vinyl over wood windows and the durability and superior insulation of the vinyl product is the overwhelming explanation given (Figure 2).

That being said, the single customer who preferred the wood alternative provided important insights. He stated that while wood requires more maintenance, “vinyl windows CAN’T be maintained at all.” He then explained this statement by saying, "I have several vinyl windows that were likely installed in the 90's (before I owned the house). The mechanisms are sticky, they don't close tightly, and the seal between panes has allowed condensation between the double-pane. These older vinyl windows cannot be repaired, they will eventually be replaced, where wood windows could be fixed up.” This response suggested that due to the lack of repair opportunities inherent with vinyl windows, wood windows might indeed be the superior long-term choice. Additionally, as all the other participants have only had their vinyl windows for a decade or less it is possible that their responses (and satisfaction levels) may differ with time. Moreover, the relatively recent installation of these five participants’ windows and the fact that
four of the five respondents have had to replace their windows suggests that a vinyl windows’ life may well be less than a decade. However, a much larger sample size would be needed to definitively conclude this. Lastly, out of the four people that have replaced their vinyl windows, two sent them to the landfill and the other two had the installer remove them. Thus through this survey we were severely limited in our ability to analyze the frequency with which windows are recycled after their removal.

The few survey results that we were able to collect and analyze have allowed us to come to a number of conclusions, however. First of all, vinyl windows are clearly part of a relatively recent trend. Secondly, while they are highly durable and well insulated for at least the first ten years of their life, their inability to be maintained past 10 years (on average) results in eventual degradation and disposal. Finally, because our results show a split between the tendency to throw vinyl windows away and to have them removed by an installer, it appears that while recycling of this vinyl product is available, it only occurs under the manufacturer’s supervision and could potentially be ineffective.

**PVC Window Disposal and Recycling: James G. Grant Disposal Company**

At least two of the customers who purchased PVC windows from Boston Building Resources had installers remove them when they were old and needed to be replaced. Because there exists a law in Massachusetts preventing the incineration or disposal of post-consumer PVC waste before it is sent to a sorting and recycling facility, BBR contracts the James G. Grant Disposal company to uninstall Harvey vinyl windows from customers’ homes and transport them to a sorting facility (G. Caplan, personal communication, Apr 20, 2015). In this facility, different strains of the material was separated, and the non-marketable ones (glass and certain metals) are sent to the incinerator or landfill, while the salvageable PVC scraps are recycled through the
processes outlined in the background (Stichnothe and Azapagic, 2013). The characterization of the material being recycled is incredibly important, for if the PVC is mixed in with unmarketable materials or is deemed unfit for recycling, it will be sent to a landfill or incinerator. Thus even in the recycling process, substantial care must be taken in sorting the waste.

**DISCUSSION**

It seems that recycling infrastructure put in place by the Harvey Plant, BBR, and Grant Disposal Company is fairly successful, but there are still several uncertainties in the process that could be rectified through a more connected relationship among these stakeholders.

If Boston Building Resources were to set up some sort of collection system in which it had consumers return their used window frames and received a deposit paid at the time of purchase, consumers would be incentivized to keep their old window frames out of landfills, reducing the amount of dioxin emitted during the slow breakdown of the PVC. This would increase the number of consumers returning old window frames rather than throwing them out due to lack of knowledge about proper disposal. The old frames would then be sent straight to a recycling facility to be reprocessed as is happening currently. However, instead of not knowing where these recycled PVC scraps are sent from the recycling facility, Harvey could work with Grant Disposal Company to keep track of the amount (likely in kilograms) of PVC sent to the facility in order to receive that same amount in the form of PVC chips to produce new window frames at the Harvey Plant. This would reduce the need for the Harvey Plant to buy virgin PVC resin from a PVC manufacturing plant, further incentivizing this relationship between homeowners, BBR, Harvey, and a recycling plant.
Another way that Harvey could more completely embody the mindset of environmental sustainability is by cutting down on their greenhouse gas emissions. Currently, at the Harvey plant in Manchester, New Hampshire, all activities in the plant are powered by fossil fuels. However, this is not the case in every plant that is run by Harvey. On their website, Harvey boasts that their warehouse in New London gets 40% of its electricity from photovoltaic cells that are installed on the roof of the building. If Harvey were to institute a companywide policy that mandated renewable energy use at each Harvey facility, the company could cut down substantially on its greenhouse gas emissions. Additionally, the transportation realm of the PVC windows’ lifecycle is another area where sizable greenhouse gas emission reductions can be made. Harvey receives shipments of PVC from Ontario three times a month, according to Mr. Swisher (T. Swisher, personal communication, Feb. 13, 2015). The windows are then shipped to Boston Building Resources distributed throughout Massachusetts. Trucks running on gasoline do 100% of this transportation. Although changing to natural gas-powered or other lower emitter models represents a sizable capital investment, when Harvey’s trucks reach the end of their life, the company could lessen their environmental impact by choosing more efficient models to use in their products’ transportation.
CONCLUSIONS

Through a thorough investigation of the PVC lifecycle this study has discovered a number of human health and environmental detriments inherent in PVC products. Research conducted concerning PVC reveals that recycling this material is the most effective way to reduce these effects, however, and this led to an investigation of Oxy Vinlys Canada, Harvey Building Products and BBR's recycling practices. Additionally, a survey was sent to homeowners that had purchased vinyl products from Harvey and was used to analyze the frequency with which the windows are being recycled, who they are being recycled by, and to what degree recycled content is being utilized in the production of new windows.

Oxy Vinlys Canada, Harvey Building Products and BBR all state that sustainability is central to their mission, and this study revealed that their current efforts reflect this promise. Although the industrial side of PVC has refined their production and recycling processes to create the smallest amount of waste possible and to responsibly dispose of that waste, the survey shows that consumer-side recycling is on a wholly different track. According to the survey, recycling is uncommon among customers and this suggested that further incentive is needed to improve the frequency with which PVC is returned to the manufacturer and able to be reused. Currently, a disconnectedness among stakeholders and the lack of knowledge among homeowners regarding the detriments linked to these vinyl windows can likely be blamed for the public's poor recycling trends, and reveals that a more integrated and educational approach to PVC window production and recycling is needed.

In addition, the use of renewable fuels would be another effective step to take in making the PVC life cycle more sustainable. Each batch of PVC travels over 900 miles in its lifecycle (not including transportation of frames to customers and to the recycling facilities); this
represents a huge potential for improvement on the transportation side. Additionally, on the production side of the process, if each company had the opportunity to switch to alternative sources of energy, like solar or wind power, their plants or buildings would significantly reduce the greater carbon footprint. Diversifying their renewable energy portfolio could be the logical next step for the company’s involved in the PVC window’s production to increase their environmental stewardship.

Finally, in order to determine how the vinyl product compared to its wooden alternative, this study collected data concerning the durability and sustainability of each product. This research revealed that vinyl windows typically require a larger initial investment, but that their superior durability and longer lifespan often won customers over and consequently outweighed the price discrepancy. Feedback provided by survey participants revealed that vinyl products could not be maintained after an average of ten years, however, which explained why nearly all of the participants had eventually replaced their windows, and highlighted the "greener" quality of the wooden option.

Through the information gathered this study discovered that while PVC products are rising in popularity, the wooden alternative remains a relevant choice and better consumer-side recycling practices are needed to reduce the environmental and health impacts inherent in the PVC lifecycle. Harvey, Oxy Vinyls Canada and Boston Building Resources have all been diligent in their commitment to environmental sustainability, but need to offer an integrated approach to post-consumer recycling, diversify their renewable energy portfolio and continue to closely monitor PVC pollution if they want their PVC windows to be considered the most truly “green” choice.
APPENDIX 1

Section A. Homeowner Survey: How Green are Vinyl Windows?

1. What is your gender?
   a. Male
   b. Female

2. What is your age?
   a. 18-24
   b. 25-34
   c. 35-44
   d. 45-54
   e. 55-64
   f. 65-74
   g. 75 or older

3. What neighborhood do you live in?

4. When were your vinyl windows installed?
   a. Within the last year
   b. Within the last five years
   c. Within the last decade
   d. More than a decade ago

5. Have you had to replace any of your vinyl windows?
   a. Yes
   b. No
6. If so, how often have you replaced them?
   a. Not Applicable
   b. Every Year
   c. Every 5-10 years
   d. Other (Please Specify)

7. What did you do with the old windows?
   a. Not Applicable
   b. Recycled them
   c. Put them in the trash or in a landfill
   d. Other (Please Specify)

8. If you have both - do you prefer Vinyl or Wood windows?
   a. Not Applicable
   b. Vinyl
   c. Wood
   d. Other (Please Specify)

9. Please explain why you prefer wood or vinyl windows.

10. Please include any other relevant information here.
REFERENCES

Anrade, Dan. "PVC Outweighs Wood in Longevity, Durability, Adaptability." 


Print.


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