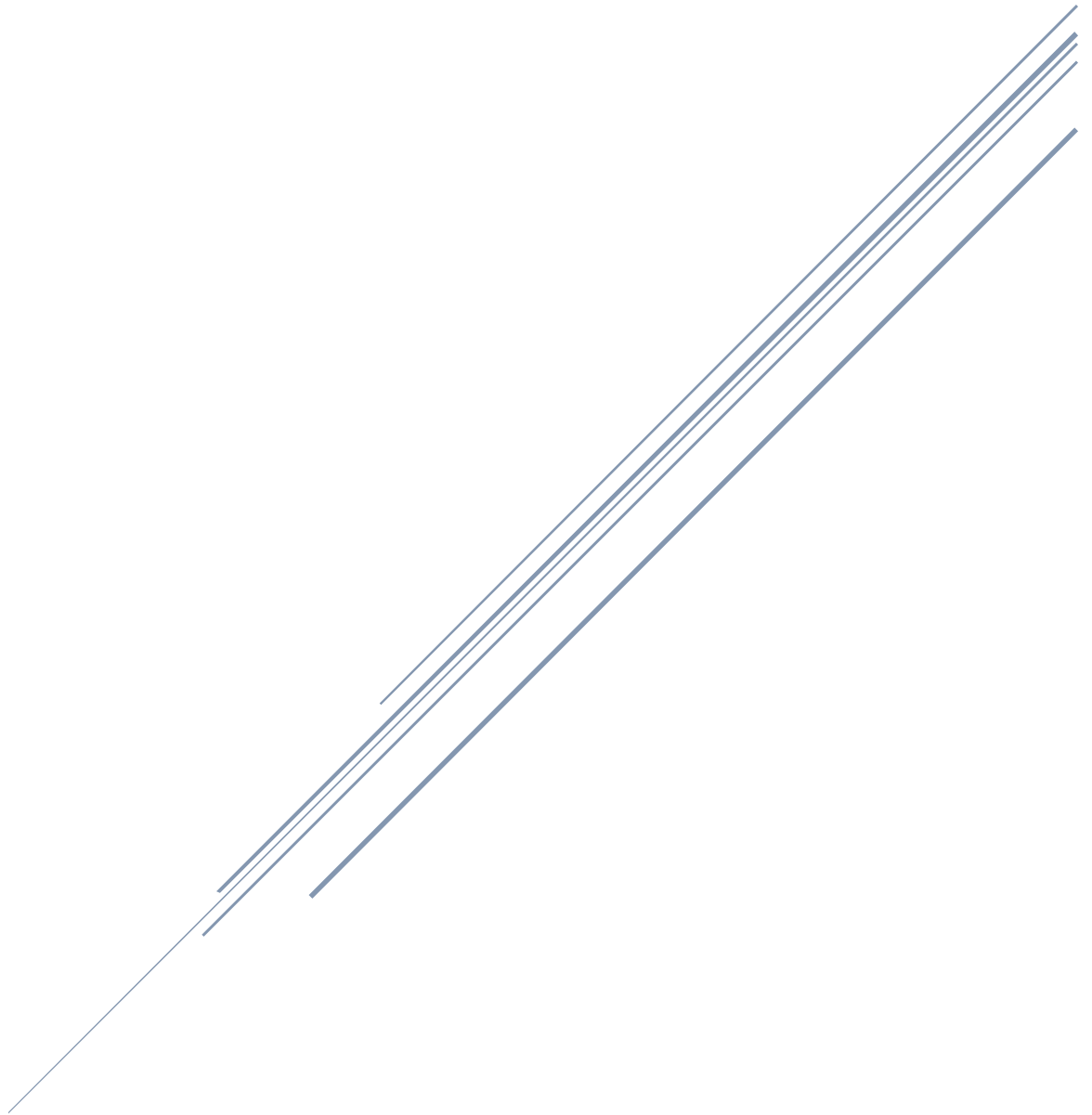


FINAL PROPOSAL

How Might We Facilitate the Recycling of Window Glass in
the C&D Industry?



Nick Bond, Adam Fultz, Stephen Haggard, Ludwika Pankowska,
Heyinn Rho, Rodolfo Saborio, Jinming Yu
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Problem Statement

How might we facilitate the recycling of window glass in the construction and demolition industry?

The Problem

In our materialistic culture, it is acceptable to waste or source more than needed, and so each person generates a significant quantity of trash each year, approximately 1,686.3 pounds per person based on a daily average of 4.38 pounds. This is beginning to prove unsustainable, and some projections put the amount of resources to be consumed in the year 2050 at approximately those equivalent to three earths worth of annual resources (United States Environmental Protection Agency, 2014, p. 1).

At the same time, recycling costs remain high. A current estimate of the cost of recycling to households in the U.S. alone amounts to \$ 6.1 billion. Recycling rates have gone up, but there are still materials that are not widely recycled.

In order to achieve the correct scope for our project, we created and analyzed a hierarchy of waste sources in the United States. We first decided to approach a problem space within the scope of non-industrial waste. This type of waste constitutes two-thirds (414 million tons) of all waste in the United States (United States Environmental Protection Agency, 2009). Next, we faced a decision between municipal solid waste (MSW) and construction and demolition (C&D). Although MSW first appeared as a better choice, we soon recognized that a project within this scope was far too broad. We would eventually have to narrow our decision to a specific material within MSW. The most wasted non-industrial material behind C&D at 160

Figure 2. MSW Recycling Rates, 1960 to 2012

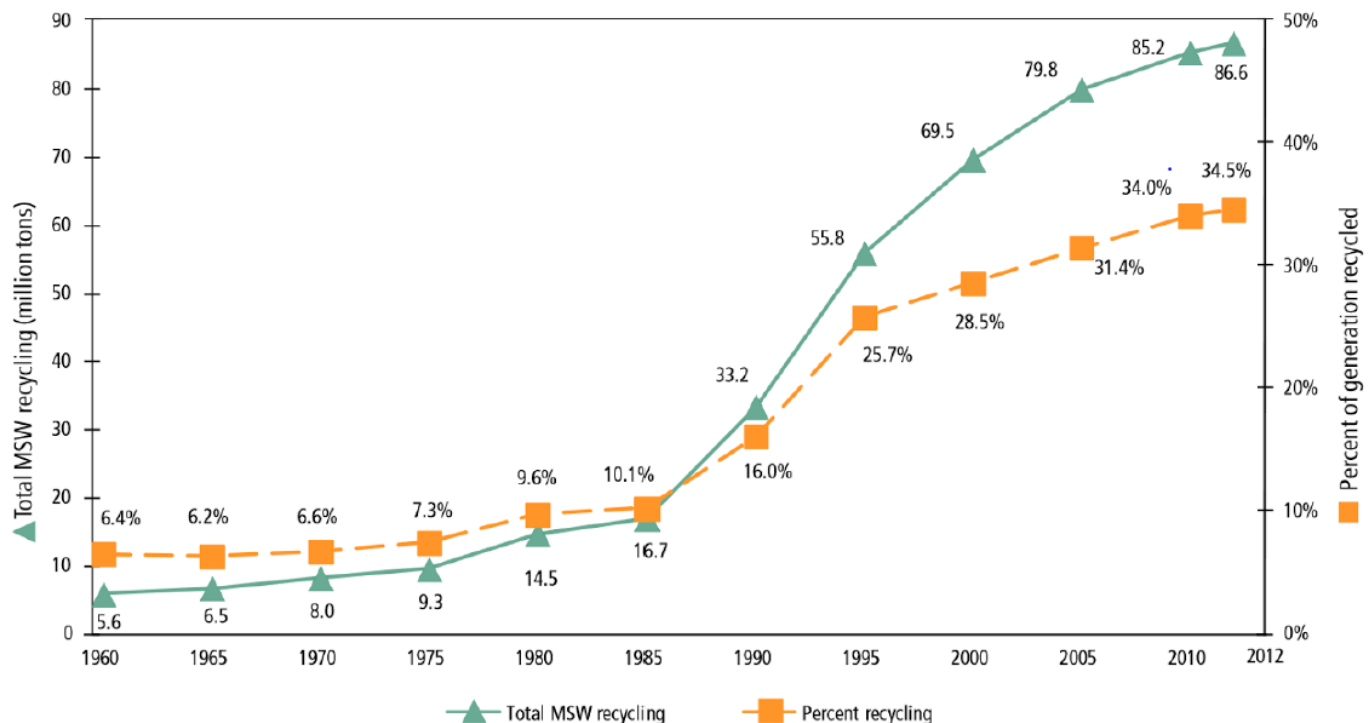


Figure 1- Graph of Municipal Solid Waste Recycling Rates. Note that these rates are showing signs of leveling out in more recent years and future projections.

million tons was food at 54 million tons (United States Environmental Protection Agency, 2014). This now large difference shown by our data between MSW materials and overall C&D conveyed a clear alternative. We looked into possible challenges within C&D and carried a unique optimism for the space we discovered. We foresaw the potential for a solution that could encompass all materials within the space. We then decided to narrow our scope to residential C&D waste. Although a smaller space than non-residential, our interview with Anne Rogers from the Office of Sustainability and case-studies of the Glenn and Towers Residential Hall projects on Georgia Tech's campus led our team to conclude that upwards of 80-90% of waste is recycled on larger, non-residential-sized construction sites (A. Rogers, personal communication, January 23, 2015). Small projects, most likely because of cost-driven reasons, tend to not have the same level of repurposing and recycling.

Then, we decided to use materials only from residential renovation projects since this waste comprised the majority of the residential C&D scope (United States Environmental Protection Agency, 2003). Out of the most common materials found in this space, we made a decision to produce a process to more effectively prepare glass for the recycling process. Although about 28% of the glass was recovered for recycling, windows panels, because of their multiple coatings, are not (United States Environmental Protection Agency, 2015). According to the Glass Packaging Institute, an advocate of the use of glass within the standards of environmental and recycling policies, "Recycled glass is substituted for up to 95% of raw materials. Without coatings, glass is 100% recyclable and can be recycled endlessly without loss in quality or purity. Over a ton of natural resources are saved for every ton of glass recycled" (Glass Packaging Institute). This specific problem space is measurable and utilizes our team's strengths in chemistry, computer science, and industrial engineering. As long as we can remove the coatings from window glass, a huge amount of resources and energy will be saved, generating environmental and economic benefits.

Since choosing this space through this process, we have concluded that the source of the window glass will not substantially affect the solution we will eventually propose. However, the data we collected on the problem space indicates that in a similar situation, residential *construction* projects, glass is less than 5% of the waste produced. This is 315,000 tons of glass from a highly specific type of project (University of Michigan). Therefore, since we are no longer limited by the source of the window glass we use, the distinctions - industrial or non-industrial, residential or nonresidential, and construction, demolition, or renovation - will have no bearing on the specificity of the space. It was important for our group to take this approach for our decision, but we have now stepped back to analyze how we might make the greatest difference with a solution for this problem space.

Causes of the Problem

The industries operating inside of our problem space value financial factors over all others. It is sufficient to look to the development model of China, India and Brazil to find that economic growth can tend to have little to no regard for environmental sustainability. A preference towards having a positive bottom line in the short term rather than a long-term mentality left sustainability out of the picture for some time. There is now a developing trend towards sustainability, largely applicable within the C&D industry, and this change is welcome. However, given this overall pursuit of profits, sustainability has experienced greater implementation in large projects, where the economies of scale justify the overhead costs of sustainable construction practices, specifically repurposing and recycling. Overlooking the

smaller projects is problematic, as it separates the consumer from these practices and their benefits and leaves a large amount of materials to waste still on the table.

How would society benefit by solving the problem?

Society would greatly benefit from the betterment of the recycling and repurposing conditions in the renovation space for consumers. Window panels are, at the moment, difficult and costly to recycle. These conditions leave the bulk of consumers out of preventing this material from joining the waste stream after their projects. Providing a process to facilitate this would have a positive impact on two fronts. Most tangibly, it would help reduce the total amount of waste joining the waste stream. Most glass manufacturers rely on a steady supply of recycled crushed glass, known as “cullet”, to supplement raw materials (*Merriam-Webster*, 2015). Cullet costs less than raw materials and saves energy because it melts at a lower temperature, which means reduced emissions of nitrogen oxide and carbon dioxide, both greenhouse gases. Department of Residential Facilities, University of Maryland states, “A ton of glass produced from raw materials creates 384 pounds of mining waste. Using 50% recycled glass, cuts it by about 75%” and “using recycled glass to make new glass cuts related air pollution by up to 20%.” Additionally, according to the Pennsylvania Department of Environmental Protection, “Recycling one ton of glass saves the equivalent of nine gallons of fuel oil” (2015). If we can succeed in creating a similarly effective procedure for window glass, money will be saved and environment will be improved. Providing consumers with cost-effective methods to reduce their renovation project’s impact would aid, in conjunction with other efforts directed towards this, in the process of educating and involving the consumer on sustainability and its benefits (social, environmental and economic).

Stakeholders

Consumers

The consumer is one of the highest stakeholders in the problem space because it is the consumer who controls the supply and demand for the recycling industry. The result has been an industry that employs over 1 million people and generates approximately \$236 billion in revenue each year (United States Environmental Protection Agency, 2001). This suggests that there is clearly demand amongst consumers for innovative waste management solutions, and that a solution focusing on adding value to the consumer has a strong chance of being successful.

Governments

A government’s main purpose is the administration of a nation’s resources towards the betterment of the economy for its inhabitants. Other than war, climate change and the state of the environment have been among the most internationally challenging issues to tackle diplomatically. Talks have been had, with the Kyoto Protocol of 1992 laying important foundations that have evolved into the talks this past September building up to the conferences set-up for this year leading to meaningful legal agreements on the issue (United Nations Headquarters; United Nations, 2014). This is a pressing issue on the agenda of many nations, and it is of relevance to them to find ways to reduce their footprint, especially given the agreements that are likely to be formed soon.

Construction Industry

The construction industry, according to Anne Rogers, a LEED certification expert working in the Office of Sustainability at Georgia Tech, has been impacted by higher

demand for sustainable efforts in construction. This signals that it is not the big construction companies that set the state of green renovation practices, but the consumers who look for these companies to carry out their projects. Given the trend towards more sustainable projects in the past decade, construction companies have had to adapt and incorporate better practices into their operating procedures (A. Rogers, personal communication, January 23, 2015). Efforts towards a more sustainable process for the recycling of glass windows would affect the industry by forcing them to adapt to a new standard or at least by exposing to the importance of the issue.

The Corporate World

The current economic model favors profits over most other rewards. Our hope is to create a process that is economically feasible so that there is not a strong clash with this sector, which also permeates to other sectors, including consumers. By presenting a strong economic case for waste reduction, the corporate world might start to follow these practices more and fund further research. This change would also benefit governments, as they would be able to devote their resources more effectively and less sparsely.

Why is it still a problem?

As with any wicked problem, the factors that work towards having it stay a problem are many. From our exploration of the problem space, a main reason this is still a problem is the economic barriers to entry for a sector of the economy. Big projects can make use of technology because the economies of scale allow for it and end up recycling or repurposing upwards of 86% of the waste, as this research team found during a recent case study on the Towers and Glenn renovations at Georgia Tech, but this is not the case with smaller projects. This also works to make another big factor more problematic, as the average consumer is not exposed to the economic benefits of green practices as often. Research dictates that an unknowledgeable consumer is less likely to push for the practices that could help improve the state of waste. By developing a process that helps reduce the cost of a recycling process for smaller projects, we would be addressing these two issues head on, which at their core are really about attaching a higher value to environmentally friendly processes and products that justifies the necessary cost hike associated with many of them.

Why Is This important?

Why Windows?
As detailed in figure 2, bottle glass and window glass (float glass) have reasonably similar compositions. (Fluegel, 2007).

Soda-lime glass composition (containers, float glass e.g. for windows), mol%

	Typical container glass	Typical float glass	Approximate limits
SiO ₂	74.42	71.86	63-81
Al ₂ O ₃	0.75	0.08	0-2
MgO	0.30	5.64	0-6
CaO	11.27	9.23	7-14
Li ₂ O	0.00	0.00	0-2
Na ₂ O	12.9	13.13	9-15
K ₂ O	0.19	0.02	0-1.5
Fe ₂ O ₃	0.01	0.04	0-0.6
Cr ₂ O ₃	0.00	0.00	0-0.2
MnO ₂	0.00	0.00	0-0.2
Co ₃ O ₄	0.00	0.00	0-0.1
TiO ₂	0.01	0.01	0-0.8
SO ₃	0.16	0.00	0-0.2
Se	0.00	0.00	0-0.1

Figure 2- Except for significant deviations in MgO content, the compositions of bottle glass and window glass are quite close.

It intuitively follows that since they are chemically similar and bottle glass is recyclable, window glass should be as well. Window glass, however, is coated with an extremely thin metal oxide layer (called a low-E coating) which serves to reflect heat/ultraviolet spectra and increase energy efficiency. These metal oxides are typically applied through two types of processes, both of which fundamentally rely on chemical vapor deposition (CVD) (Gordon, 1997):

1. Pyrolysis- A vapor containing primarily tin oxide is bonded to the glass while it is still molten, which creates a hard outer layer adsorbed into the glass. This coating is typically 10-20 times thicker than a sputtered coating.
2. Sputtering- Multiple layers (typically 3-13) with different compositions are applied to cooled glass in a vacuum chamber, resulting in a somewhat softer coating than a pyrolytic coating. The result is a film one ten-thousandth the thickness of a human hair.

Bottle glass, which does not have this low-E coating, is easily melted down and re-formed into new bottles. However, if one attempts to melt down glass with the low-E coating still adsorbed, the chemicals will interfere with the crystal structure upon reforming, rendering the recycling operation useless. If there were a way to remove the coating from this glass, then we believe that the current recycling process applied to container glass can also be used for window glass (Efficient Windows Collaborative, 2015b).

How Glass is Recycled

Currently, the process for recycling glass is relatively straightforward and requires few complex chemical transformations. After consumers throw glass in their recycling bin, it is taken to a treatment plant, where a magnet is passed over to remove any pieces of metal in the glass mixture. From there, an optical sorter separates the different colors of glass (which differ slightly in composition and cannot be mixed together) and cleans them to remove any impurities before the reprocessing begins. Next, the glass is crushed finely into cullet and mixed with additional soda ash, sand, and limestone. This mixture is heated to around 2,600-2,800°F and molded into its new shape (United States Environmental Protection Agency, 2015). This process is efficient enough that a ton of carbon dioxide is reduced for every six tons of glass recycled (Glass Packaging Institute). And perhaps most noteworthy is the fact that glass is one of the only materials that does not degrade in quality over time. This is both a blessing and a curse, as glass can be recycled infinitely many times, but if thrown away, it will not decompose. Therefore, we see glass as a resource with significant recycling potential that is big enough to make a large impact in the C&D waste problem space but small enough to be within the reach of our team, RENTEC.

Goal

By the end of the project, we hope to develop a process for removing the coatings from window glass in order to make them recyclable. This process will be geared towards the average

consumer in such a way that our process might be used by public waste companies such as Waste Management so that their consumers can recycle windows. Furthermore, our solution would be able to directly expose the public to the benefits of recycling. If successful, our solution has the potential to divert several hundred thousand tons of waste from the landfill; saving money/energy and reducing the impact of our society on the planet.

Objectives

Develop a Process that Cleans Window Glass

Background: The first phase of the process that we propose to develop is cleaning the glass. Especially if installed or removed by careless workers, most windows are in some way contaminated with outside materials such as paint, sealant, or other renovation debris. Regardless of what kind, these contaminants pose a huge threat to a recycling operation, as even a very small amount can poison an entire batch of glass, ruining as much as several thousand pounds of otherwise recyclable glass. We hypothesize that cleaning the glass before the second phase will maximize the efficiency of our process in the end.

Methods: Since some of the chemicals that may have contaminated the window glass that we will be recycling have very strong adherence, and so a traditional “soap-and-water” surfactant cleaning (where an added chemical reduces the surface tension between water and the contaminant, acting like a detergent to remove the contaminant) may not be effective. Instead, our proposed approach is to use a stronger solvent to dissolve anything that may be on the glass; a chemical like acetone that is inexpensive, not terribly toxic, and possessing stronger dissolution properties than water. Our preliminary design of this process phase uses acetone to clean off crushed glass that is fed into the system, shown below. It is unknown whether or not any of the acetone coming out of the process (the stream labeled “spent acetone”) will be recyclable.

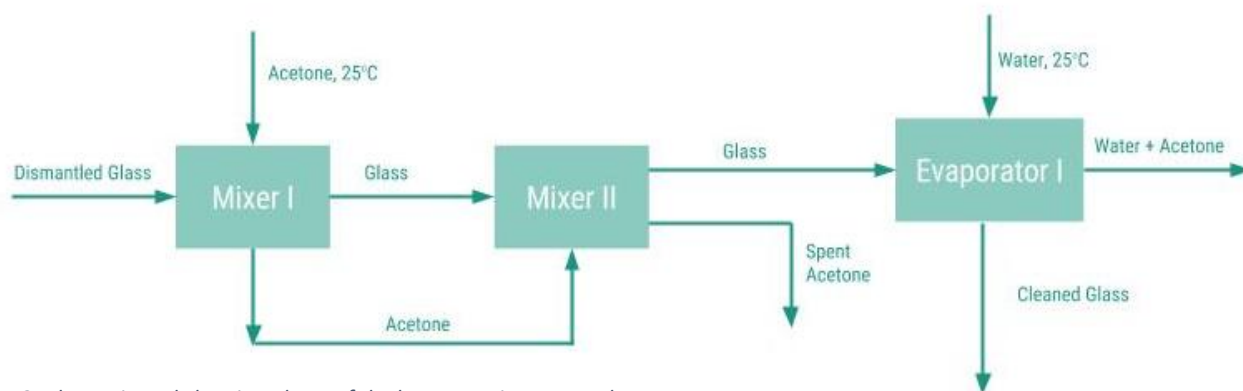


Figure 3- The projected cleaning phase of the low-E coating removal process

Outcomes: Success will be determined by prototyping this phase of the process, particularly the sub-unit that tests our choice of solvent and/or surfactant. If the chemicals we are using are successful, then the glass should appear clean, and common contaminants such as vinyl/acrylics, glycols, and calcium-containing salts should be present in the cleaning solution. Since many potent organic solvents have very high vapor pressure, it is reasonable to assume that the spent solution from a cleaning test can be

evaporated, leaving the contaminants behind, and demonstrating that the process phase was successful.

Anticipated Problems: One possible problem is determining how much solvent is needed to clean its respective quantity of glass, a ratio that will probably be dependent on the conditions under which the mixers operate, which we have not yet determined. There are empirical data available for us to initialize our experiment. However, collecting the external database may be time-consuming. Deciding which informational source to rely on will be a matter of finding a scheme that best fits our research background. This step especially requires well-coordinated group discussion. Another potential issue is ensuring that the cleaning agent is removed from the glass before the second phase starts, a problem for which we plan on using an evaporator to clean and dry the glass before we attack the coating.

On a different note, the cleaning phase of our process contributes to the efficiency of overall glass recycling but equal amount of attention should be paid to the steps that come after the cleaning. The cost of running one experiment is high since we will be focusing on one recycling procedure at a time. Therefore, planning experiment instructions that will most effectively utilize the chemical materials and observable reactions is critical.

Develop a Process that Removes its Low-E Coating

Background: After successfully cleaning the glass, an operation with which we currently propose using acetone as a cleaner/solvent, we need to initiate a process to remove the coating on the glass so that it can be recycled. This is a critical step in the overall process, as a failure to do so will ruin any attempt to recycle the coated glass.

Methods: Chemically, the low-E coatings applied to window glass are rich in metal oxides that can typically be reduced to water-soluble metal chlorides. By undergoing a reaction at the coating surface that chemically alters the coating components, we expect to see significant desorption of the metals present. From there, we

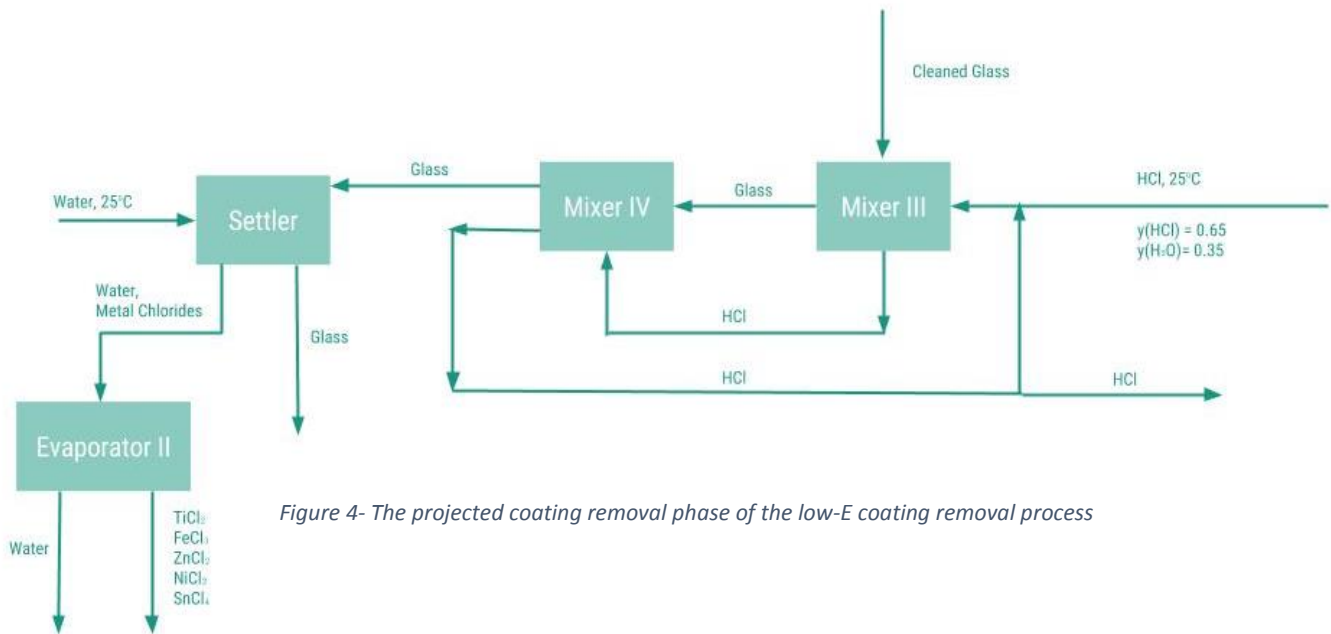


Figure 4- The projected coating removal phase of the low-E coating removal process

plan to use an easily accessible protic solvent, such as water, to dissolve the resulting metal chlorides and effectively remove the low-E coating from the metal. In short, we believe that this part of the process will require 2 basic steps: selective reaction of metal oxides in coating, then followed by a separation process to remove reaction products. The following shows our preliminary design of this part of the process (phase II of process flow diagram).

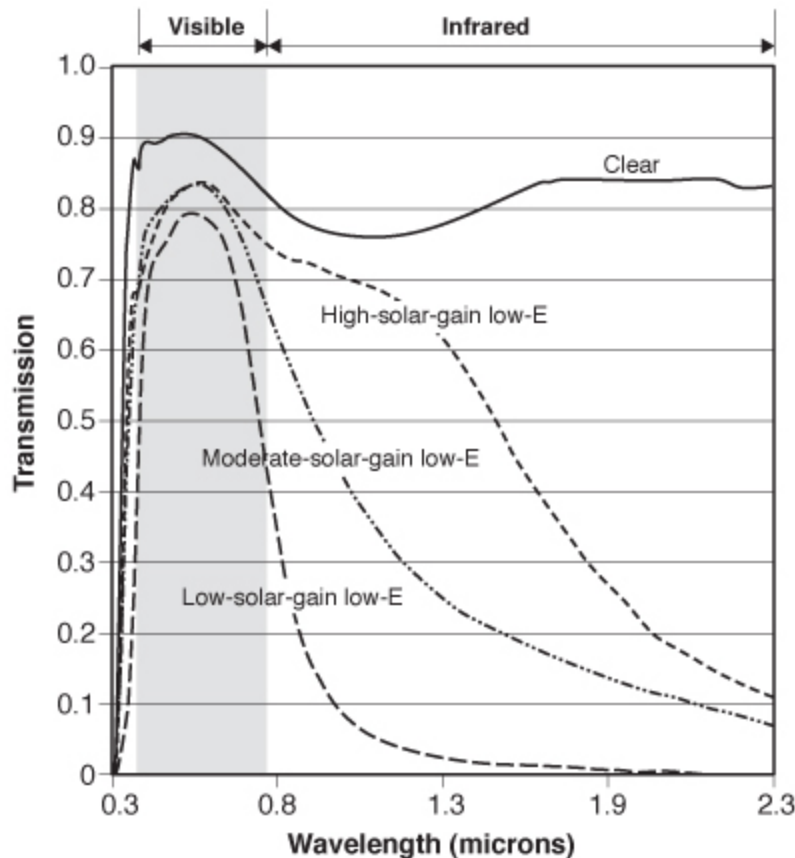


Figure 5 (From Efficient Windows Collaborative, 2015b). Analysis of transmittance of window glass with no coating versus low-E coatings of various solar gains (the fraction of incident radiation admitted through a window, a lower solar gain transmits less heat)

Outcomes: Determining the success of this phase of the process will be determined by prototyping and testing our process. We plan to test individual process units separately, then assemble the overall operation, to ensure that each step is successful. If successful, then we should see different readings for the transmittance of window glass once its coatings have been removed, in accordance with figure 5. (1.) In addition, we can test the success of our process by adding aqueous salts such as sodium carbonate that will precipitate metal ions out of solution if they are present in forms such as NiCO_3 or $\text{Fe}_2(\text{CO}_3)_3$, since the respective chlorinated salts are water-soluble.

Anticipated Problems: Acquiring the equipment to test this phase of the process may be difficult, as well as designing the test apparatus itself (the mixer, heaters, etc). While our current design is based on a well-balanced mix of productive effectiveness and cost-efficiency, more complex chemistry may be required to completely remove the low-E coating from the glass. This is by far the most difficult part of the problem, one in which we will probably need the assistance of our faculty contacts. However, it also presents the greatest opportunity to really create a novel process that will be accessible for the consumer.

Create High Value for our Process

Background: Making our process valuable is perhaps the most important objective of our project. While it is reasonably simple to develop a process to accomplish our first two objectives, developing one that creates value by accounting for economic and environmental considerations is much more difficult. From our research, we understand that cost is pretty much the only factor driving market demand for waste disposal processes. Therefore, if our solution is to be effective, it must be economically competitive with the alternative, throwing window glass away.

Methods: In order to complete our task, we will need to perform a full analysis of the costs associated with landfilling a ton of glass versus performing our process and recycling a ton of glass, both in the short run and long run (even though short run costs will be given primary consideration in evaluating the value of the processes). This cost analysis will first consist of primary and secondary research to provide competitive intelligence on the costs of currently existing solutions. Second, after developing our process, we will evaluate the costs of our own solution, both in terms of continuous costs and the immediate overhead cost that implementing our process would accrue.

Outcomes: The end result will be a determination of whether or not our process has established a strong value proposition that will make it a successful competitor in the C&D waste management market. Should our analysis determine that our solution is not valuable enough to be successful, we will need to go back to the first objective and re-evaluate the process design to see where we might improve our efficiency.

Anticipated Problems: While there is value added in our solution by helping out the environment and reducing long-term cost, the consumer does not always make rational economic decisions and is prone to purely focusing on cost.

Develop Working Relationships with Organizations in the Problem Space

Background: No matter how technically impressive or cost effective our solution is, its impact will be limited by our ability to push it to market effectively. In order to do this properly, we believe it is necessary to start developing partnerships with organizations that work within the problem space. Two ideal organizations for our purposes are: the Lifecycle Building Center and Habitat for Humanity ReStore. These two engage consumers in trying to reduce what goes into the construction, demolition and renovation waste stream. The data they could provide us in terms of scale and

accessibility of window glass and other materials would prove very valuable during both the research stage and the implementation one.

Methods: We have already contacted the Lifecycle Building Center and will shortly be contacting Habitat for Humanity. We hope to get a response from them a set a meeting time during this semester to discuss the potential impact of the project we have in mind, offer our help in their efforts and ask for help with ours. If neither of them agree to engage with us as partners, we will continue to look for a suitable partner. Once a partnership is established, we will start the community engagement and data collection process in order to get primary source data on the market we will be engaging with first. Developing these relationships has the objective of a smooth implementation of the technical processes we are developing in mind.

Outcomes: After engaging with a partner or partners we hope to have gathered sufficient actionable data for the implementation of our technical solution. By the end of a year, we hope to have had a positive impact at least in raising awareness and engaging with consumers about the possibilities for waste reduction in the renovation space. Any data we gather that may be of use to the general public will be made available in a convenient way to whomever wishes to access it. The most desirable outcome, however, is to have a partner sufficiently engaged to directly help with the implementation of our solution.

Anticipated Problems: Given that this is the softer side of our project, lots of unknowns and uncontrollable factors come into play. The first and most dangerous deterrent to the success of our project would be the lack of a partner during the research stage. It might be that none of the companies we contact want to establish a partnership with us. If we do engage with a partner, however, there might still be problems. For one, the partner might be more interested in having our team aid us than in aiding them. We might also find that the data we collect from these partners is insufficient to be used in the implementation of the solution.

Research Team

Our Team

Our research team will consist of members specializing in two different concentrations: testing/developing the technical solution and studying the socio-economic considerations of this part of the problem space.

The first group will be tasked with designing the process that we propose to execute. These members should have significant laboratory experience and are likely majoring in chemical engineering, chemistry, or materials science and engineering. In addition to strong synthetic skills, these team members should be proficient researchers who can further develop and critique our process by exploring contemporary scientific literature in the problem space.

The remainder of the team will have two main goals. The first will be to establish working relationships with different organizations and companies in the Atlanta area. An industry partner is a valuable asset, able to deepen our understanding of the market in addition to being a potential platform for the implementation of our solution. The second goal is focused on analyzing the costs (both monetary and environmental) and perceived value of our solution as it is being developed, providing information that can help our technical group design a better process.

Possible Advisors

We hope to gain both valuable insight into our problem space and lab access for developing our solution. One of the best ways to do this is to seek help from the faculty at Georgia Tech, several of whom specialize in fields related to ours. We have started reaching out to them, and over the next few weeks, hope to identify a strategic partner that will advance our team into process engineering and testing.

1. Dr. Ryan Lively- Faculty member in Chemical Engineering. While his research (alternative separation processes for the petroleum industry) is not consistent with the work that we propose, he has expressed interest in answering some of our more technical questions and connecting us to several of his colleagues (contacted 3/30/15).
2. Dr. Valerie Thomas- Faculty member in ISyE and Public Policy. Her work focuses on the impact of sustainable practices and the socio-economic connotations surrounding them.
3. Dr. Rosario Gerhardt- Faculty member in MSE. She focuses on producing and characterizing polymer/ceramic composites in a variety of applications, in addition to analyzing and assembling nanoparticle films. We think her extensive knowledge of materials characterization techniques and film/coating syntheses will prove to be a valuable asset for our team, as well as possible source of lab access. (contacted 4/14/15)
4. Dr. John Muzzy- Faculty member in Chemical Engineering. In addition to chairing the Multidisciplinary Polymer Engineering Program, Dr. Muzzy researches composite materials both through developing innovative techniques for their production and analyzing their properties. When we are ready to develop a new coating for window glass, we think that Dr. Muzzy will be one of the best resources if we choose to go the polymer/MOF route.
5. Dr. Dong Qin- Faculty member in MSE. Dr. Qin uses colloidal science and surface chemistry to synthesize nanocrystals intended for a wide range of applications such as electronics, imaging, catalysis, and biomedicine. She seems interested in our ideas and has already commented on several aspects of our initial process design. (contacted 4/14/15)
6. Dr. Kenneth Sandhage- Faculty member in MSE. Dr. Sandhage is an expert in functional coatings synthesis, including multi-component metal oxide coatings such as those found on windows. We think he could be a key resource for identifying the exact composition of low-E coatings used on residential glass and how we might best remove it.

Timeline:

In order to better plan out the process for developing and implementing our solution, we have constructed a timeline consisting of objectives that we think can be met in the specified time. Of great importance right now is finding a faculty mentor and 1-2 more members to add to our team since 4 of our members will be leaving.

Spring 2015 (End of semester)

1. Identify and contact potential faculty mentors
2. Determine which team members will continue into the fall
3. If necessary, find and interview new team members

Summer 2015

1. Confirm faculty mentor and access to lab space for prototype development and testing
2. Secure research for the summer for further project development (Nick)

- a. Testing possible chemical reaction sequences to develop a prototype

Fall 2015

1. Test chemical reaction sequence to verify its effectiveness
2. Begin development of process units that optimize chemical reactions and necessary physical processes

Spring 2016

1. Finish process unit development, begin connecting and testing units in sub-processes
2. Develop full prototype of overall processes
3. Begin scaling process and analyzing performance/costs
4. Begin seeking partner for process implementation

Summer 2016

1. Continue process scaling and testing
2. Find partner for process implementation for Fall 2016

Budget:

Materials and Supplies

1. Chemicals/Raw Materials
 - a. Hydrogen chloride gas cylinder (might be available in-lab)
 - b. Acetone- proposed solvent for cleaning glass (\$7/gallon)
 - c. Window Glass- substrate for cleaning process (donations expected)
 - d. Sodium bicarbonate- for precipitating most aqueous metal ions out of solution after removal for glass surface (\$51.20/kg), used for quality control testing
2. Stream Transport
 - a. McMaster-Carr Extra-Hard Stainless Steel Tubing, # 9773T18 (\$19.61/ft) and 9773T11 (\$13.75/ft) (<http://www.mcmaster.com/#standard-metal-tubing/=wqyqxn>)
 - i. Doesn't require welding
 - ii. Withstands high pressures and very high temperatures (max 800°F)
 - iii. ½ in. diameter for glass shard streams, and ¼ in. diameter for fluid/vapor streams

Equipment

1. Available in Lab (no cost)
 - a. Spectrophotometer- identifies metal oxides present on glass, used to test composition of coating and verify its removal post-process
 - b. Fume Hood- important for chemical safety, especially when working with hot HCl vapor
 - c. Distillation Unit- allows customizing of stream purity, useful for producing HCl vapor from hydrochloric acid
 - d. Heaters- heats product streams to appropriate temperatures

- e. Metalware and glassware- for basic testing of chemical reactions outside of process units; helpful for evaluating kinetic and thermodynamic considerations
- 2. To be Purchased
 - a. Munson Machinery Mini Rotary Batch Mixer (no price given) (<http://www.munsonmachinery.com/products/mixing/rotarybatchmixer/minirotarybatchmixers/index.asp>)
 - i. Can process small quantities of material (less than 15 ft³), ideal for prototyping
 - ii. Quality and mix times scale up to high-capacity mixers; System performance can be accurately projected for larger systems

Services

- 1. Conversion of mixer to support continuous streams after batch testing. May require manufacturer to customize or purchase new equipment altogether.

Travel

- 1. Resource Recycling 2015- September 28-30 Indianapolis, IN
 - a. This is a global conference that addresses the state of the recycling industry in a variety of sub-disciplines, tailored down to a specific focus by the attendees. It brings together groups who we think possess valuable information and could greatly enhance the success of our project, such as the American Chemistry Council, the Recycling Innovators Forum, and the Environmental Protection Agency. We think that this conference will prove to be a valuable networking opportunity and a place to refine and share our knowledge and research gained over the summer.
 - i. Registration- \$505 (covers 4 meals, refreshment breaks, conference packet, admission to all sessions, tradeshow, and evening reception)
 - ii. Air Travel- estimated at \$300 round-trip
 - iii. Hotel- Onsite hotel is Indianapolis Marriott Downtown, for \$179 per night (double occupancy)

Context and Existing Solutions:

Glass recycling is a common process that has been already utilized in the past decade. We know that Glass is 100% recyclable and can be recycled endlessly without loss in quality or purity - given that the glass that is being recycled is not stained, affected by previous coating (are contaminated) or the recycled glass pieces are too small to meet manufacturing specifications (Glass Packaging Institute).

Window glass falls into the category of the glass that is hard to recycle as it is in fact “contaminated”. Because windows protect the inside from UV radiation and are made in order to keep the temperature stable inside the house the windows have to be specially coated with certain chemicals and outside materials. There are many companies that take care of recycling the regular glass in a cost effective way and there are also companies who started taking care of the window glass that has been contaminated. In our research we found two big glass recycling

companies that address this problem: Strategic Materials and Dlubak Glass. Both of these companies take in vast amounts of glass waste such as: glass bottles, window panes, automotive windshield glass, lighting industry glass, container industry glass, CRT glass, and many more (Dlubak Glass). Both of these companies recycle vast amounts of glass and have their results. The only problem is they are only available for big companies and big consumers (Strategic Materials, 2012). They do not provide their services for an average person who has to discard their waste. Because their services are altered for tons of glass waste they are not able to be sufficient with small amounts wasted glass materials. Also the locations of their recycling plants are very limited.

Outcomes:

What will success look like?

Our project involves multiple elements that have to be worked on and developed. Apart from establishing an efficient process of removing the non-glass components from the windows and separating them from the framework, we must involve small consumers in the recycling process. Consumers will then motivate companies to invest financially and technically.

If we manage to establish and create a feasible and cost-effective process of non-glass component removal that is scaled to the appropriate consumer we would have accomplished our goals. Currently, success is to establish a cost effective process for removing non-glass components from the window glass that does not require huge amounts of wasted glass in order to carry out the process like Dlubak Glass or Strategic Materials does. In the long run we want to see our project help the environment by reducing the amount of glass that goes into the waste process. If we are able to establish a cost effective process on this small scale for the average consumer we will see the effects in the long run. By developing a good networking system and partnering up with small companies such as the Life Cycle Building Center we hope to come up with a way to get the consumers more involved in the recycling process of specifically window glass.

How will we assess this?

We will assess our success by testing out our chemical process on certain discarded glass materials and seeing how effective our non-glass removal is. We will see whether the residue is removed and whether we get the glass into its original state. After this is accomplished we will continue our partnership with the Life Cycle Building Center and see if our procedure is economical and accessible enough for small companies and the average consumer to get all of the window glass to be recycled properly. If we see that people are actually using our process and that the small business contacted approve of it we will be able to say that we accomplished our goals.

Anticipated Problems: One or more problems that could come up during the way

Developing the glass recycling process as we imagine it involves significant chemical experimentation and testing. Since we are somewhat inexperienced in our technical fields, we may have difficulties gaining access to a lab in which to develop our process. Thus, our team must consider that alternative solutions are possible. Utilization of computer simulation is a technology that can lower the cost required to carry out the project while we are seeking for funding.

Recycling business is low in terms of competitiveness. Because of the lack of peer pressure, our method will take longer than usual to get distributed over time. Considering

we are only freshmen in college, it will be hard for us to persuade the first company to adopt our procedure. Hence, increasing the prestige of a research group and gaining evident sponsorship plays a significant role when we are asking for more companies to support us financially.

Some of the unexpected and unintended expenditure may be due to equipment failure during experiments and the insurance coverage for potential lab accident. The chemical waste and lab garbage created must be disposed properly. The legal and ethical responsibility for using chemical resources may impose limitation on our lab experiment. There may also be technical roadblocks, a central element of our proposal is a process that is cost effective and attractive to smaller scale projects. While removing a low-E coating is not necessarily a difficult process to imagine, creating an environmentally friendly one that is also low-cost might be. It may prove difficult to find a good balance between the effectiveness of the process and how efficient it actually winds up being.

Our team may heavily rely on communicating our idea to expert researchers. This requires frequent team meeting in order to make a group decision on which experimental path to take. External communication with lab supervisor also affects our behavior as a team. The supervisor may impinge on the team's independence and the team may lose control of direction the project may be taking. The team members must learn when to resist supervisors' advice and when to accept the advice. Depending on the individual's personal relationship with the lab advisor, one group member may work more closely with the advisor than others.

Because our project will be a joint effort with advisors engaged in research, our project will need to follow the research timeline. The research objective should acknowledge the current barriers besetting the process of recycling glass. For this reason, our project may deviate from "glass" and take on a new but related topic as our research focus. Deviating too far from the "glass" is risky because we have been tailoring our solution to fit the glass industry.

Our project intention goes against the flow of current glass technology development. Through collaborating with faculty at Georgia Tech, we hope to address this possible roadblock throughout the design and testing of our solution.

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