The Effects of Advanced Ceramic Materials on the Recycling Industry

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Nathaniel Craft
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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Motivation for Research

Through-out human civilization, we have only been able to progress by using the available resources around us. Without resources civilization cannot grow and expand to become larger and more complex. Modern day civilization is running into a shortage of current materials. As our society becomes more complex and looks towards different accomplishments, more and more resources are consumed. With this rapid consumption, there are signs of some resources reaching the end of their natural deposits (Collins, n.d.). As these natural deposits are depleted, Humanity will have to find ways to either find new resources, or reuse what we still have available. One area of the different resources that is tied with the United States plans to move deeper into space is the use of advanced ceramic material. These materials are used to protect different parts of space vehicles as they experience different thermal extremes.

Through policy analysis and wicked problem framing, research of ideas and programs set in place by other countries to deal with the recycling of dangerous advanced ceramics for thermal protection and how the public interacts with systems put in place has been performed. In order to analyze how the public would interact with new recycling policy and how the public interacts with the current lack of policy in the US, the ideas put forth by the Social Construction of Technology have been used. SCOT shows how the public guides the work done to drive recycling technology in either a good or bad direction. These materials, unlike ceramics used for public use, like plates and pottery, are not safe in manufacturing or as they break down in the environment. The United States policy on ceramic and glass recycling is already lacking in impact and efficiency (“Why glass recycling in the US is broken,” n.d.). In order to tackle this lack of policy, this project will answer what the United States can do to prepare for the recycling of complex ceramics in the future when they become more prevalent in manufacturing.

Research Question and Methods

How will the US prepare for the safe recycling of ceramics in the future when they become more prevalent? This question is answered using different research methods. One research method is policy analysis. Using policy analysis, I am able to see America's policies on recycling compared to the policies of other countries and even between states and cities within America. Policy analysis has given insight into why the US has a lack of recycling policy currently, however this analysis required a serious look into many connected policies and political ideas (Browne, Coffey, Cook, Meiklejohn, & Palermo, 2018). Wicked problem framing is another useful research method. This method helped to incorporate the different connections from seemingly unrelated issues to shed more light on why there is not as much of a drive for recycling of these materials. Additionally, wicked problem-solving aided in the understanding of the large societal impact that reforming a recycling system for even just a city would impose ("Wicked Problems: Problems Worth Solving—Wicked Problem," n.d.). These research methods help to further define and understand this problem. Wicked problem solving brings the different factors into light, and the analysis of different policies helps to give an idea of what other countries are working on as opposed to where we stand on these issues.

Through these methods, an argument was developed by searching out specific articles, statements, and plans made by other countries. Using policy analysis and searching for key phrases relating to countries with successful recycling policies, an analysis of successful systems was performed. Analysis of how different scientific journals talking about different proposed recycling technologies intersected with the growth of policies in countries such as France and Germany lead to an understanding of how research leads to more efficient recycling methods in those areas.

Using a wicked problem framing of these ideas, the impact these same policies had on the public of United States cities was examined. There are many different factors affecting this implementation, from the social aspect of a lack of education about recycling to the corporate problem of turning over recycling operations to the government for better control and regulation. These areas of the wicked problem of recycling policy are addressed and discussed. Most information tied to these areas has been researched through searching for the affects small towns and cities had when their recycling policies were introduced, and attempting to scale up from there. Wicked problems are difficult to tackle, as there is no set solution for the problem in the end, and they branch out into more problems, but using this as a starting point for the societal impact of such recycling policies will help to understand what path to take (*Wicked Problems: Problems Worth Solving—Wicked Problem*, n.d.).

Methods and Questions from Part 2:

Restating the question being asked, how can the United States prepare for the influx of complex thermal protection ceramics that are currently being researched to be put into commercial and active military use? Once these engines, and their environmentally toxic ceramic components exhaust their use, they will be decommissioned, however, this decommissioning will only sit and eventually be spread into the environment unless there are active plans to reclaim these materials and components. The main method used to analyze this problem is policy analysis. By viewing the policies of other countries with successfully implemented recycling policies, and framing these through a wicked problem analysis lens, these policies can be applied to America's current recycling problems (Browne, Coffey, Cook, Meiklejohn, & Palermo, 2018, "Wicked Problems: Problems Worth Solving—Wicked Problem," n.d.). Due to the lack of national recycling policy in America, there is little push for recycling research that has been

implemented, and as such, analysis of proposed complex ceramic recycling research would not be as useful, until policies concerning the current recycling problems have been implemented. In order to help in the Wicked Problem analysis and framing, the Social Construction of Technology is implemented in order to understand how these policies may affect America, and how the United States has become so sluggish in implementing recycling policies and technologies.

Background Information

Recycling in the United States as a whole lack in both policy and implementation (*The US Recycling System Is Garbage*, 2019). More specifically there is no system for the breakdown of inorganic ceramic waste that has started to become more commonplace in research applications (Kamiya et al., 2007). Many ceramics already contain dangerous materials, in the form of silica that can be found in pottery and some ceramic kitchen ware (*TOXNET*, n.d.). Silica is a basic component in most ceramic applications from basic pottery to the highly specialized ceramic composites being used in high temperature engine applications. Given the lack of recycling policies for ceramic material, the increased study and use of more harmful ceramic material will need to be addressed in the near future. These materials are necessary as development of air travel and power generation on land leads to higher temperature turbine application. With these higher temperatures however, materials need to be created and tested that can perform in these environments. The metals that are currently used in these systems cannot handle to heat produced by these combustion cycles, however ceramics can. These ceramics are different from the ceramics used in pottery but contain some of the same basic components. These ceramics still use silicon and silica as their basic building blocks, but will incorporate

other rare earth ceramics that can be harmful to people and wildlife (Padture, 2019). Some of the components included in these ceramics are Yttrium, Ytterbium, Carbon Black, and Indium (Padture, 2019, *Indium—Element information, properties and uses | Periodic Table*, n.d., *Carbon Black*, 2018). These materials are dangerous to human life, both during manufacturing and as they break down and enter the environment. As ceramics are exposed to the hostile environment of the turbine engines, they will begin to break down. As ceramics break down, they create oxides that have their own dangerous, and glass composites of many different materials that will remain for years before breaking down completely in the environment (Padture, 2019).

Given these dangers, it is vital to begin looking for solutions to the problem that will eventually be an abundance of these no longer functional ceramic engine components. However the US doesn't have recycling policies set in place for basic ceramics or any waste currently produced. Recycling falls onto the individual states and cities to tackle this issue and find solutions (US EPA, 2015). Due to this lack of national pressure, many states have little to no recycling policy, and manufacturers control what they buy back from reclamation, and whether or not they will consider buying reclaimed materials at all. Material reclamation has become its own industry due to this lack of control, allowing businesses to charge cities extra just to collect recycling, whether they will end up using it or not, where as in France citizens are incentivized to recycle, gaining benefits and lowering their disposal charges through this (Sultan, 1997). This is another problem facing our current recycling system, a system that definitely will not be able handle an influx of dangerous materials coming from government and industrial processes and products.

STS Framework

Analysis using the Social Construction of Society (SCOT) allows the recycling of these materials to be put into the perspective of the people affected. Originally, sociologists of science theorized that the fundamentals of even the fundamentals of physics are determined through the negotiations amongst different groups to come to a common ground of understanding. Trevor Pinch and Wiebe Bijker took this a step in another direction to say that technological artifacts could be the result of different groups coming to a common understanding of what was needed, or wanted, by society (Klein & Kleinman, 2002). Through this framework it can be understood that if a major group in a society doesn't have any need for a specific area of technological development, then that development will be slow to progress, or may not progress at all. This lack of progression would be due to the lack of motivation or interest groups, lack of funding from potential investors, or lack of education in the subject.

One of the major aspects of SCOT is relevant social groups (Klein & Kleinman, 2002). In order for technology to be socially constructed and guided, there have to be social groups invested in the technology and the impact it will create. Social groups can be anything from the institutions and engineers designing the technology, the regulatory commissions defining the bounds of acceptability of the technology, or the consumer buying and applying the product for the intended purpose. These groups interact and influence the production of the technology. If the consumer doesn't invest in or buy the technology, then the engineers have no reason to work on it, leading to regulatory commissions not defining its place in the market. These groups may also have a differing definition of what defines working when describing the technology that is being constructed. Without a consensus on the technology's final outcome, the technology will never truly be completed.

Another aspect of SCOT that has less of an impact, but still an implication in this dilemma, is the framework of closure and stabilization (Klein & Kleinman, 2002). A technology will never be leaving the design stage if groups with vested interests are unable to decide where the problem ends. Because of this, the group may elect to move the goal post of the problem. The definition of the problem that a specific artifact or system solves does not necessarily have to be static. In some cases, the problem being addressed can be molded in order to make the decision of a fitting technology an easier one. In this case a technology could solve one portion of the initial problem, leaving the other part of the problem open to new exploration by the prevelant social groups.

The fourth and final aspect of SCOT addresses how the social groups interact with one another in the background of the artifact's development. This area of SCOT was not originally touched upon by Pinch and Bijker when formulating the beginnings of SCOT and has thus been an area of growth and criticism (Klein & Kleinman, 2002). Interactions between groups can help to influence how each group thinks about the artifact in production, and could implicitly or explicitly control the process of design and finalization. Groups with more power could sway other groups to change their opinions or silence their opinions on how the technology is crafted and used, effectively shutting out the smaller affected groups.

One major criticism of SCOT however is the reliance on groups and their contribution (Klein & Kleinman, 2002). As stated by Klein and Kleinman, "Implicitly, SCOT assumes that groups are equal and that all relevant social groups are present in the design process.". This is rather obvious since not all groups associated with an artifact's development have the same sway, or even a voice at all when it comes to development besides their general and economic support. This criticism can be taken further by stating that SCOT as a framework could lead to a

lack of involvement of certain social groups, since the framework shows that they barely affect the development, but would overall be affected by the outcome.

Results and Discussions

To find a solution to something a future impending problem it is best to see how similar problems are tackled. In the case of recycling complex ceramics, the best place to look is current recycling technology and policies for common ceramics. In order to prepare for these kinds of problems in the United States before we are overwhelmed by not only common recyclable items, but dangerous complex ceramics, we should adopt policies similar to the countries of Europe that lead the charge in recycling technologies and practices. Additionally, the production of the ceramics requires large amounts of energy to produce. Glass making requires temperatures between 1400 to 1600 degrees Celsius in order to be formed, requiring large amounts of fuels to keep hot (*Glass Making*, n.d.). Reduction of the use of fossil fuels can help to push recycling technologies into main stream use, due to the recycled materials being cheaper to acquire than processing raw materials. These methods as well as the push back they have received and could be predicted to see will be detailed further in this discussion.

The first part of this discussion is analyzing how countries such as the United Kingdom, South Korea, and Germany have been so successful at their recycling endeavors. A key factor across different policies is the incentive created by the government for the people to begin to recycle their glass and ceramics, and reuse as much as possible. Germany's recycling system makes the process simple by using different color bins for the different color glasses and financial compensation is offered for returning reusable recyclable bottles as well (*Glass recycling in Germany*, n.d.). In the United Kingdom, specifically in Scotland, there are reverse vending machines and manual drop off points for the glass and ceramic recycling (*Recycling*

policy, 2019). Scotland additionally gives compensation for different amounts recycled back to the consumer as incentive to keep recycling, and uses public works to keep littering low and give citizens a higher appreciation for nature (Deegan, n.d.). In rural parts of Scotland and other countries in Europe, appreciation of the natural scenery is taught by the older generations and understood by the younger generations to keep litter and trash that could be recycled off of the roads and out of nature. The strategy of "Towards a Litter Free Scotland" helps to keep this system of education as time goes on to keep the recyclable litter being reused.

South Korea is another major contributor to glass and ceramic recycling. South Korea implements a mandatory glass recycling policy where all citizens bring their glass and ceramic recycling to designated drop off and pick up points. The incentive for this system is the taxing of the mass of the garbage that will be picked up from each residence. This is another example of incentivizing citizens to recycle based on monetary gain. This incentivization of the citizens is a common theme amongst the top ceramic recycling countries. This incentivization comes from a combination of higher taxes and less raw materials needing to be shipped into the country due to the control the government has over how much the industries are allowed to import, forcing them to use the recycled materials in order to produce products. These similarities show the effects of how policies of the top recycling countries operate (Smit, 2015).

In order to understand why American recycling technologies and European recycling technologies have differed, the framing of Social Construction of Technology (SCOT) was employed. In order to complete this framing, certain things have to be understood. One thing that needs to be understood is that the United States has been selling the recycling and trash that was produced to Chine for three decades. As of 2018, China is no longer accepting our barges of waste and have been sending the backlogged barges back to the states (*The US Recycling System*

Is Garbage, 2019). This has caused an abrupt and damaging change to the system the United States has been working with for the past 30 years. This reliance on China accepting our recycling and waste together as one lead to an apathy in educating people on what could actually be recycled. During the time that China accepted our waste, anything placed into recycling bins would be sent to China all together with the trash, that China would sift through. Most recycling these days is very specifically combed through in order to find the items that are most profitable, which does not always lead to everything put into bins being recycled (*The US Recycling System Is Garbage*, 2019).

An additional difference to what the United States does not implement is Government run recycling. In European countries and South Korea, the recycling companies are normally subcontracted by the government, or are part of the government in order to keep an eye on the industry and allow it to be profitable (*Recycling policy*, 2019, *Glass recycling in Germany*, n.d.). The United States does not have any national policy on recycling or recycling companies and corporations. Because of this, the companies decide what they will take in, and will work towards profitability rather than protection and preservation of the environment (*Why glass recycling in the US is broken*, n.d.). This is in part that currently in the United States it is more profitable for the manufacturers to import raw materials than to buy reclaimed materials through recycling centers (*Is what we're recycling actually getting recycled?*, 2008). These factors hep us to understand the basis for the SCOT framework. Due to China accepting just about anything from the US, there was never any reason for the public to become informed and push for anything to change. Presently there is little being done to educate the citizens on what they can recycle and what they can't. There are educational systems, but they have to be sought out, as

opposed to someplace like South Korea, where families are taught what to recycle by the government.

Because of this lack of education, there is no drive by the affected group of the citizens to push other affected groups like the government and research institutions to actually work towards. A study by the National Waste and Recycling Association shows that the American people could benefit from more education on what needs to be recycled and how (*Americans Can Benefit from More Recycling Education – Study*, 2014). This education would help to increase the quality of what is recycled and how much can be sold back to other manufacturers without being up-charged to solve the heavy sorting needed to find useful materials in currently recycled items. Using SCOT, we can see that without this education, no forward momentum is being caused by the largest relevant social group, the consumer. Even though the consumer will be most affected by the destruction of the environment by the influx of dangerous ceramic products and other recyclable items, if there is no drive to fix the problem, then the technology will never be produced.

There are researchers working to develop new ways to recycle dangerous ceramic products (Ribeiro et al., 2001, Kamiya et al., 2007, Lin & Bai, 2013), but the technologies do not have enough backing by the government or the general consumers in order to drive the technology forward into widespread use or for the finalization of the product. One aspect of SCOT focuses on the finalization of the technology through each relevant social group understanding and agreeing what the function and result of the technology needs to be. However, if one of the relevant groups is sparsely educated and differing on opinions, then the technology will be pushed farther into research and production until there is more knowledge of the problem by relevant groups and consensus on the solution. It can be seen in other countries that SCOT

had the opposite affect of what is happening in the United States. Once China stopped accepting waste from everyone, the governments of South Korea, Germany, and other countries started implementing methods of collecting recycling effectively and thoroughly, and education the public on what can be recycled and why it is necessary. These efforts united the relevant social groups of the government, industry, researchers, and consumers to work together to develop systems of sustainability that are still growing and improving today. The main hold up for the United States is the lack of education of the average consumer. This education would help to instill the urge to fix the problem, and do what is necessary to alleviate the recycling drawbacks we see today.

The answer to the problem tackled in this paper is not going to have a singular answer, nor will it be easily implemented. In order to be ready to tackle the influx of complex ceramics and glass waste produced by the growth of space travel and hypersonic travel industries, we have to start by dealing with the lack of recycling policy and industry in America right now. As a country we lack a national recycling policy, leaving the decisions of the different policies up to individual states and cities (US EPA, 2015). Due to this, the recycling industry in the United States is very privatized, leading to different corporations charging the city and consumers for taking in recycled materials, and deciding whether they keep the material to try to reclaim the items collected (*Is what we're recycling actually getting recycled?*, 2008). The first step to solving this problem is to develop a policy of a national control of the recycling industry. This would allow for more subsidies for recycling startups, as well as a better control of what they have to take in, since the government would be paying for the companies to take this material in. In connection with this, and possibly a harder policy to implement, would be the reduction or a higher taxation of the raw material imported into the United States for production. Doing this

would allow recycling companies to hold more weight when they offer reclaimed materials for industry, allowing a higher profit to be turned.

In addition to a policy giving the government a hand in controlling the recycling industry, which mirrors there ideas put forth in Germany and South Korea (*Glass recycling in Germany*, n.d., *Single Blog—Paceglass*, n.d.), A policy should be put forth mandating education on recycling for public schools. The more education on the impacts of recycling that can be given, the more the public will understand what can and cannot be recycled, what helps the environment, and what technologies are used in the recycling industry (*Americans Can Benefit from More Recycling Education – Study*, 2014). As referenced in the previous writing focusing on SCOT, education of relevant social groups helps to bring all groups onto the same level of understanding of what technologies are being used and what challenges are being faced. This education will help to drive the social construction of technology forward due to the relevant social groups knowing what will be necessary to move forward with the production and finalization of recycling technologies. An important part of SCOT is that the technology is finalized, and understood by all relevant social groups for what it is that the final form of the technology does. Most Americans think that just about anything that isn't food can be recycled (LeBlanc, n.d.), Education on recycling and national policies making recycling easier will help to give Americans a better idea of what can and cannot be recycled, as well as easier access to recycling bins and centers.

Once policies are implemented that help to deal with the recycling problems facing us currently, we can start to look towards the future. Aircraft industries have already taken great lengths in reclaiming older and decommissioned aircraft (*AERO - Airplane Recycling Efforts Benefit Boeing Operators*, n.d.), additionally, current tests using high temperature ceramic

components cannot be simply tossed, though they cannot be recycled as they need to studied. In order to assess and actively deal with the problems these technologies pose as they are discovered, research and processes should begin development now in order to be ready for the influx of decommission private spacecraft and decommission hypersonic vehicles. Developing reclamation strategies for these technologies will allow them to be easily implemented into an already robust recycling network, caused by recycling policies implemented now. Of course, this will not go without difficulty, but with time and energy already used to create the recycling system, the problems faced with implementing this complex ceramic recycling will be solved without having to worry about the system itself.

This project faced a number of limitations, namely the lack of research relating specifically to the problem. While there has been research done into the reclamation of complex ceramic waste, none of it has been implemented, or taken much farther than a laboratory setting. Unfortunately, this leads to lack of examples in which this problem interacts with society and industries. Another limitation is the reliance on focusing on other recycling problems in order to build a solution to this problem. While it was useful in understanding the state of recycling as of now, it led to a large reliance on current recycling as a topic in order to relate to something that has not necessarily started to happen yet. Overall the limitation of this project is that the proposed problem has not become a decision facing the public like plastic and glass recycling is currently.

I already work in the field on ceramic research, and know first hand how dangerous some of these materials can be on people and the environment. This is what originally brought me into this topic through research on what should be done with older research materials. As I move forward with the research I do, I will be mindful of not wasting supplies I have, as they are in

rare supply, I will also search out different programs interested in recycling in this field of engineering and try to help in any way I can. Other researchers in different fields should start to look into how their materials are being disposed of, and thinking about whether they can be reclaimed at the end of their lifespan, as well as keeping this in mind while designing. This problem is not only going to face ceramic recycling in the future, but recycling of many different future technologies.

Conclusion

Recycling of complex thermal protection ceramics is not a single answer problem. This problem requires the implementation of different policies, looking to reform a currently broken recycling system in the United States, and to educate the public on the necessity of recycling and what can be done to move forward. This problem is not one that we can see, but planning for future problems can be just as important as solving current problems. The last thing we as a country need is for the recycling problems of the future to compound onto our problems we already face today. Part of looking towards a future of a cleaner environment depends on recycling and reusing of materials and products, but we can't face the problems coming up without a solid method to approach and deal with them today.

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