Analysis of Aluminum Recycling through the Social Construction of Technology

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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

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Introduction

Although aluminum is the most common metal found within Earth's crust, engineers and scientists have only begun producing it on an industrial scale within the last 150 years (Schlesinger, 2013). Humans extracted and used aluminum on a large scale well after they began utilizing copper, bronze and even steel. Why was it that society took so long to develop such a common metal? One large problem facing aluminum use was its refinement from its natural ore: Bauxite. Refining bauxite into pure aluminum is difficult and very energy intensive (Donoghue et al., 2014). However, a large advantage of using aluminum is our ability to recycle it without using too much energy. Aluminum has a low melting temperature and general homogeneity which produces beneficial melting and mixing properties, essential for recycling. Figure 1 demonstrates the energy costs required to produce primary aluminum (directly from processing bauxite ore) and process secondary aluminum (from recycling of aluminum scraps) (Schlesinger, 2013). The ease and capabilities of recycling aluminum allow it to be the second most used metal in modern society despite the difficulties in refining the ore. Thus, aluminum recycling is a critical technology to analyze.

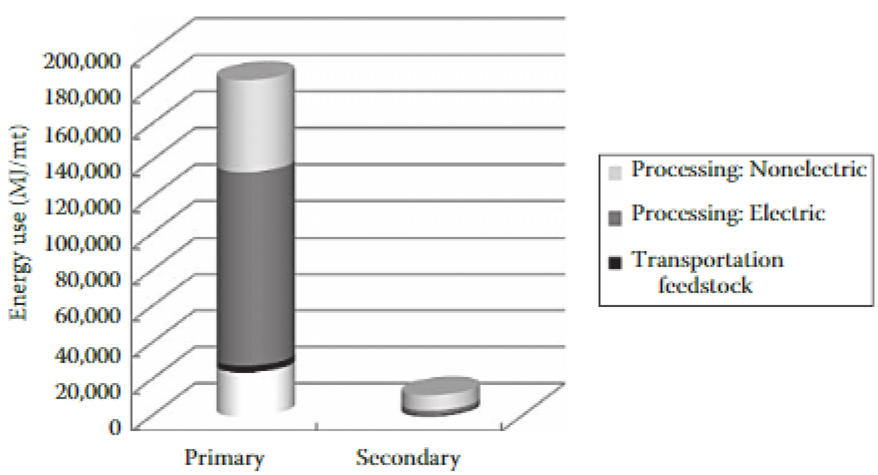

Figure 1. Demonstration of the different amounts of energy required to produce aluminum in megajoules per megaton of aluminum. The energies are also categorized into transportation and processing (Schlesinger, 2013)**.**

How does aluminum recycling thrive in our modern social environment? In this paper I will discuss modern aluminum mining and recycling processes and, through looking at both historical accounts and modern views, I demonstrate how social interactions and demands between various social groups define the entire modern recycling process through the social construction of technologies (SCOT) framework. I begin with an overview of my methodology, including how I performed the research. Then, I summarize multiple different sources used for the application of the methodology. Lastly, this paper will connect the sources to the SCOT framework and then conclude on the efforts through a discussion of connections and further analysis.

Methodology

Bijker and Pinch developed the SCOT framework to demonstrate how technology and society are interconnected, especially when it comes to the development of technologies. SCOT argues that all technologies, or in this case technological processes, are constructed through a combination of social factors. Aluminum has multiple different facets, and separate social groups each have different ideals and goals for it. Because technology addresses various social problems, conflicts often arise from differing criteria imposed by the different social groups, which results in design differences within the technology. Eventually, the technology collapses in on a single design in a process known as closure. Bijker and Pinch introduced multiple forms of closure, including rhetorical closure and closure through redefinition of the problem. Rhetorical closure occurs when the goals of technology have been "met" and the problems “solved” for most, if not all, social groups. The technology in question does not necessarily need to solve the problems, it only needs to seem like it. A second closure mechanism is closure by redefinition of the problem where rather than the technology solving the original problem, it solves a different, more meaningful problem. Closure of the problem is not indefinite. New problems or different social groups often arise, starting a new design cycle (Wiebe Bijker et al., 2012).

I will address aluminum recycling and connect it to the SCOT framework through a multitude of sources and methods. To properly analyze recycling, I will also analyze certain aspects of aluminum mining as a comparison point. First, I will provide an overview of the mining and recycling processes through analyzing the history of aluminum recycling and mining in general then considering multiple case studies relevant to the subjects. This will lead to identifying social groups relevant to the subject as well as relevant methods and designs for both recycling and mining of aluminum. I found relevant articles of both broad historical data and case studies through the University of Virginia’s library system. Additionally, I conducted interviews with students attending the University of Virginia to gauge various opinions about recycling in general. Furthermore, for the SCOT analysis, it is important to understand what sorts of problems different social groups think recycling solves. Thus, I will identify important issues within recycling and mining and then identify social groups and how they may respond to these issues.

Results

Aluminum History

I combined multiple sources to form a coherent history of aluminum processing. These include sources like Selwyn’s contributions to the Smithsonian Scholarly Press. Selwyn states that the earliest mentions of aluminum trace back to 1808 and Sir Humphrey Davey's work on batteries which lead to the conclusion that the mineral alumina (referred to by Davey as alumine) was a metal oxide. He then proposed to name the metal alumium (Humphry Davy, 1808). Frank Wöhler then isolated the metal in 1827 through taking aluminum chloride and utilizing the more reactive potassium metal to electrochemically reduce the aluminum to its solid state(Frank et al., 2009). At this point, scientists could not make the metal on any industrial scale since the necessary materials (aluminum chloride and potassium) were already hard to produce. Cheaper salts and metals allowed for enough aluminum production to construct parts out of the metal. However, the production processes still rendered aluminum rare enough that its cost compared to the cost of gold. Scientists began to make more improvements including utilizing the reduction of molten sodium aluminum chloride using batteries. The first extraction process which was commercially viable started to come about in 1886 when Hall and Herlot independently devised a method to extract aluminum from aluminum oxide (alumina). A couple years after, in 1888, the Bayer process was patented and could purify alumina from bauxite, an essential aluminum ore. Taking the ore, refining it to alumina using the Bayer process, then extracting aluminum metal through the Hall-Herlot method is still the main way we obtain aluminum today (Selwyn et al., 2019). As seen in Figure 1, the ore refining process is relatively energy intensive with a total of around 180,000 megajoules of energy per metric ton of aluminum produced.

In modern times, there is an alternative to obtaining aluminum from bauxite through using a different kind of "ore": scrap. The recycling process is analogous to the extraction of aluminum metal from bauxite. I used a textbook by Mark E. Schlesigner to analyze modern and historical technologies and problems in recycling. Aluminum recycling began several years after aluminum itself was being produced industrially around the beginning of the 20th century. It began through directly taking aluminum scrap and putting them in foundries already making aluminum from ore. Around 1910, foundries started being built with the sole purpose of recycling. Aluminum produced by these foundries were initially considered to be of lower quality due to mixing of different alloys and poor impurity removing processes. However, as time went on, the quality of recycled, or secondary aluminum rose and thus the value in recycling aluminum did too. Modern recycling processes have multiple paths to undertake. Aluminum recyclers recycle various stages of materials for varied reasons. For example, aluminum forges often remelt the edge trimmings of aluminum sheets in a process known as in house recycling. Other methods include what many think of when they think of recycling: the finished lifecycle of a product is sent to recycling centers to remelt (Schlesinger, 2013).

Public Health

The current processes of recycling allow for reduction in energy costs, emissions, and public health risk when compared to aluminum obtained from mining and reefing of bauxite (primary production). For example, Ning Ding and collaborators estimate that primary production releases 15,300 kilograms of carbon dioxide per megaton of material produced while secondary production releases only 702 kilograms per megaton, a 95.4% reduction. Secondary production has even higher rates of emission reduction when looking at other common emissions like carbon monoxide or sulfur dioxide. The lifecycle analysis by Ning Ding and collaborators also estimate that secondary processes reduce the total human toxicity potential of emissions by 99.2% when compared to primary processes. Figure 2 demonstrates further environmental comparisons(Ding et al., 2012).

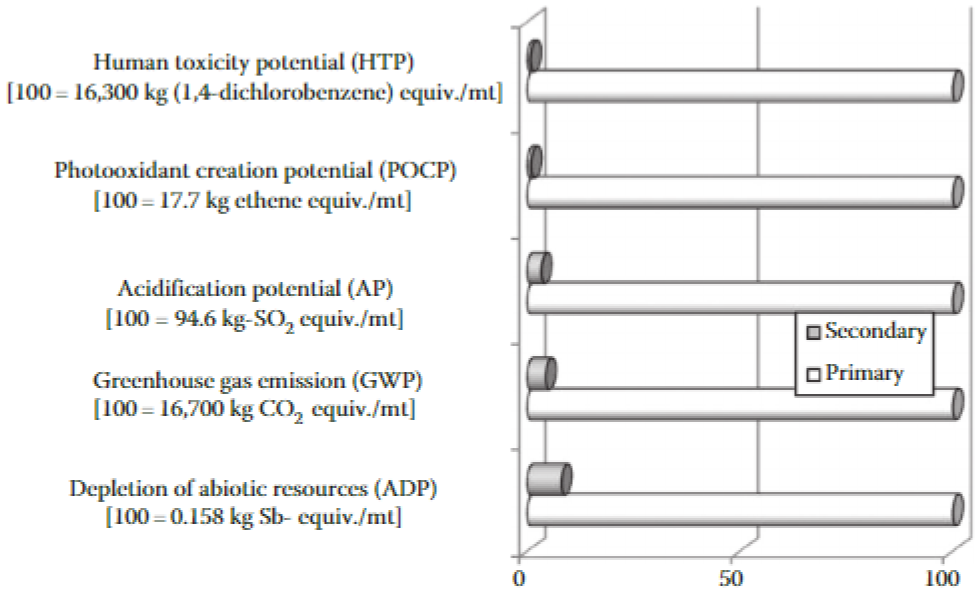

Figure 2. A comparison of various environmental impact factors between primary sources of aluminum (bauxite mining and refining) and secondary sources (recycling) (Schlesinger, 2013)

Safety

A possible caveat is the health risks associated with workers in the aluminum industry. In terms of mining safety, aluminum typically outperforms other mines with regards to safety. Those working in bauxite mines have a relatively low injury rate compared to other mines like coal. This is because the ore is typically found near the surface (1-2m in depth) since surface environments are more conducive to the ore formation (Donoghue et al., 2014). Beyond the safety risks involved in mining, the refining of alumina can also present certain risks. However, when considering the comparison between mining and recycling, the health risks posed by alumina from mining match the health risks involved in the refining of scrap collected from recycling. The major difference is that recycling requires the collection of scrap which carries higher levels of risk. Figure 3 displays a history of serious injury rates. The injuries from the recycling (secondary) industry occur at nearly twice the rate as compared to the mining (primary) industry. The discrepancy between mining and recycling scrap metal is due to the unpredictable nature of scrap: many aluminum parts contain fluids within them which can lead to possible explosions during the melting process (Schlesinger, 2013).

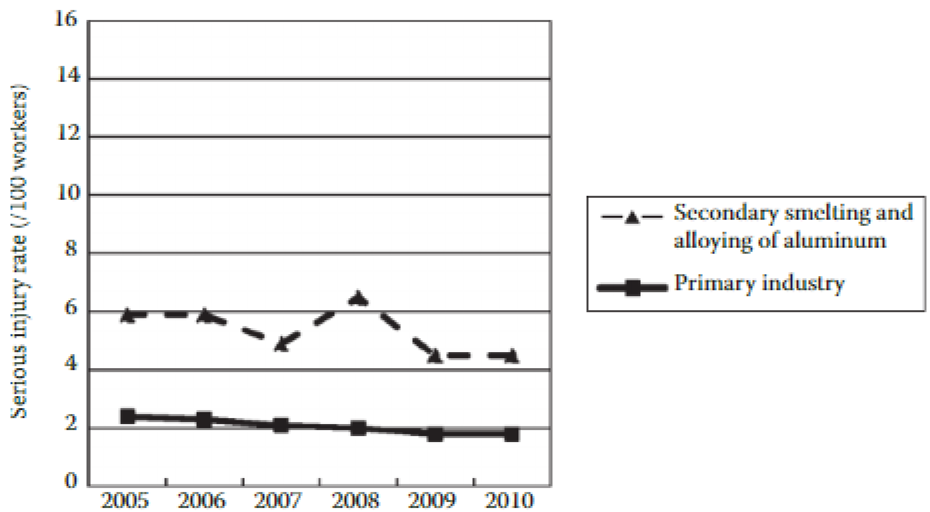

Figure 3. A comparison between serious injuries in secondary and primary aluminum industries across 2005 to 2010(Schlesinger, 2013)

Economics

Energy, health, and environmental costs are not the only considerations for the viability of recycling. Economic costs play an important factor in the viability of recycling. The price of recycled aluminum depends heavily on the alloy of aluminum. The composition of aluminum determines the specific aluminum alloy designation and therefore alloys with expensive alloying elements become more economically viable to recycle. Depending on the alloy, the sell price for recycled aluminum products can vary between 80% of primary aluminum to almost 150%. The cost of the scrap itself also varies highly on alloy content with various grades of scrap costing only 15% of the same material from a primary source while others can cost up to 90%. For an example of this, let’s look at 6061, a high-performance alloy with expensive alloying elements like silicon, which is used in heavy duty structural applications like aircraft frames (Cavallo, 2023). Its scrap cost is around 85.6% that of a primary source while a secondary product is 125.1% that of a primary product as of Spring 2010. Furthermore, scrap costs make up around 80-85% of the total recycling costs so therefore it is economically viable to recycle 6061 aluminum (Schlesinger, 2013).

Case Study: Brazilian Quilombolas

Aníbal Arregui describes how one of the largest aluminum mines in Brazil has collided with a local Quilombola community. Quilombolas are a group of people in Brazil originating from slaves who have escaped plantations. These Quilombolas span a wide region across all of Brazil but the focus of this article is on a specific community in Boa Vista which has territorial disputes with an aluminum mine. The mine, known as Mineração Rio do Norte (MRN) extracts approximately 80 million tons of bauxite (i.e., the main ore mined for aluminum) a year and is one of the largest exporters of aluminum ore in the world. The article makes an argument that the aluminum mine has significantly affected the Quilombolas of Boa Vista in a negative way. This is not uncommon to aluminum or steel mines as often the land area taken up by these mines requires some sacrifices. In this case, the bauxite mining initially affected the Boa Vista Quilombolas by interrupting the nut harvest but continuously affected the day to day lives of the Quilombolas. This happened through the Boa Vista Quilombolas working for the company town and through MRN enforcing rigid behavioral rules on them. This story is like many other stories of bauxite mining and is an important aspect to analyze as higher levels of aluminum recycling results in lower demand from mines such as these (Arregui, 2015).

Case Study: Peri-urban Managua

Alex M. Nading follows the artisanal recycling practices in peri-urban Managua around 2008, demonstrates that aluminum recycling enables poorer sectors to work with metals without the high cost of mining. Managua is the capital of Nicaragua and in 2008, the metalworks sector in Managua collapsed. These practices of collecting and remelting scrap were ways for families to produce aluminum tools, parts, and art without the need for industrial ore refining processes. Recycling here refers to both the remelting of the scrap and the use of the melt to create new parts. These families often recycled in very informal ways as they would hone skills in making individual products rather than working on some industrial scale. They were further unofficial as they often did not have licenses for metalworking and could operate without paying taxes or without public health complaints from larger governments. The recyclers also did not look for formalization through some sort of cooperative work with the government but rather sought artisanal recognition and reputation. The parts they built fit well into a demand arising from political turbulence as metal parts produced industrially came hard to come by or too expensive for many of the residents in Nicaragua. Furthermore, the rising tourism industry meant that there was a market for parts that contained bits of uniqueness that handmade parts could provide in a way that industrial parts could not. The honing of skills, like in any other art, also allowed for unique skills from one recycler to another, meaning each could be sought after for different parts. A material like aluminum allows for these practices to exist, with the extraction of the ore being too expensive while having a relatively low melting point compared to steel such that casting and forging operations on recycled material does not require as much energy (Nading, 2011).

Interviews

Lastly, I conducted several interviews with students at the University of Virginia. There were not enough interviews to produce any sort of statistics, however it was enough to get a sense of what the public understood about recycling. From their point of view, recycling is a technology meant to reduce waste that goes into a landfill and find it a sort of personal responsibility to help save the environment. Many would even hold onto recyclable materials hoping to eventually find a recycling bin if one is not directly present. All the interviewed people also mentioned how they learned about the phrase "reduce, reuse, recycle" in early schooling. Lastly, they understood what sorts of materials can be recyclable, yet often did not understand any differences between the various materials once they went into the recycling bin. The interviewees did not know which materials would require higher amounts of energy to recycle and did not really think aluminum recycling to be much different than plastic recycling.

Analysis

The initial stage of applying a SCOT framework involves demonstrating that the design of the technology has multiple interpretations depending on the social group being influenced (Wiebe Bijker et al., 2012). The process of recycling demonstrates this interpretive flexibility as many average people see recycling as a means to reduce waste while larger institutions may look towards recycling to save on material cost since it is less energy intensive. The case studies analyzed in the previous section also go to show that some, like the Brazilian Quilombolas, may view aluminum mining as an interruption of their way of life. Others like the artisans in peri-urban Managua see a different form of recycling as a sort of way of artisanal expression. This highlights how aluminum recycling has different problems to solve depending on the user's social status and their location within the world.

Social Group Influences

For the general public, recycling is seen as a solution for problems regarding environmental conservation. Recycling is an idea promoted within schools when discussing actions everyone can take to make the world produce less waste. For example, members of the public, including those I interviewed, hear about recycling through schools when introduced to the "reduce, reuse, recycle" saying, where "reuse" and "reduce" also perform the same task of lowering total landfill waste or wasted energy. Furthermore, the public understand that they can recycle many different materials including plastic paper and metal. Distinguishing the differences within each category is often beyond the scope of their efforts and thus may wish to simply dump their recyclables into a single collectable known as single stream recycling. Also, many members of the public do not understand that recycling of aluminum becomes a complex problem involving assessment of different aluminum grades in order to minimize loss of quality.

Another environmental effect of recycling is reducing the demand for mining. Figure 4 demonstrates how recycling now contributes a significant amount to the consumed aluminum and thus means there is a lower demand for bauxite mining under the same aluminum demand (Schlesinger, 2013). This leads to lowered energy requirements as recycling is a less energy intensive process than refining the raw ore. Additionally, there is a reduction in the environmental impact of the land used for mining. Beyond appealing to the wishes of the public, this directly affects social groups like the Brazilian Quilombolas mentioned earlier as mines displace fewer communities.

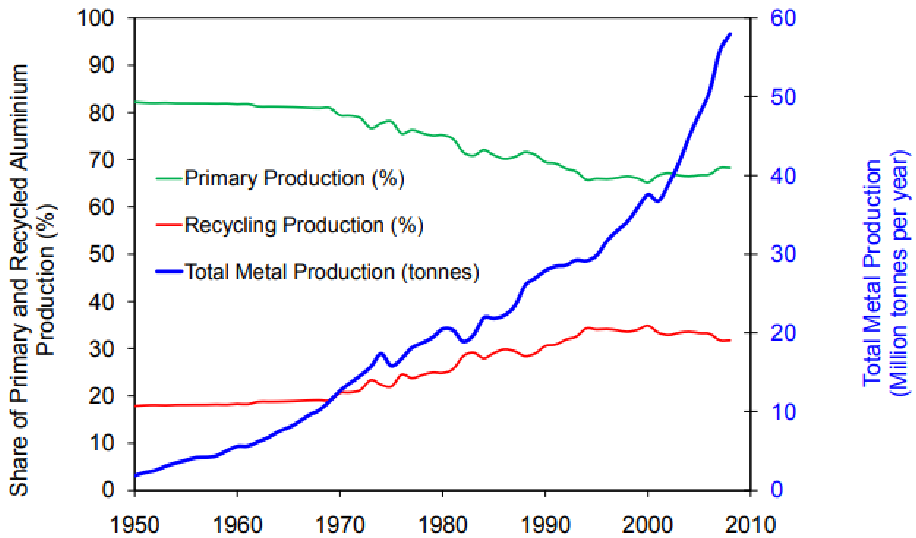

Figure 4. History of global share of primary and recycled metal production as well as total metal production(*Global Aluminium Recycling: A Cornerstone of Sustainable Development*, 2009)**.**

On the contrary, another social group that is affected by mining demands are workers who work in either mining or recycling industries are also affected through recycling as those working in scrap collection for recycling experience more injuries than their mining counterparts. Those interested in worker safety may actually prefer a higher rate of mining due to this fact.

Additionally, many recycling companies have separate desires for recycling. Profit drives these recycling companies, which results in building infrastructure only in areas with enough materials to justify the costs. "…recycling is not a religious activity. It is not carried out by people who are trying to save the planet. Recycling is carried out by people and organizations who are trying to earn a profit" (Schlesinger, 2013). This results in less industrial recycling in rural areas and a focus on materials worth the cost of retrieval. For example, wires are often difficult to process for recycling and often go unrecycled. Furthermore, the loss of quality that the public did not know of becomes of utmost importance, as lower quality material means a smaller profit margin.

Producers of aluminum products require purchasing of aluminum to create their products. A broader range of suppliers can result in lower aluminum prices and allow them to make more products at a cheaper price. Furthermore, the quality of aluminum is a very significant factor as engineers must build structural parts to safety and strength standards reliant on material properties within the aluminum.

Summary of the Problems

The main problems which recycling seeks to address can be split down into two general categories: environmental and economic. Environmental includes reduction in waste product and reduction in energy use/emissions associated with attaining new aluminum metal while economic problems include a reduction in cost to attain new metal and a guarantee of metal quality for application. Social groups that focus on the first set of problems include the public along with those negatively affected by mining directly like the Brazilian Quilombolas while social groups that focus on the economic problems include the recycling companies, the manufacturer of aluminum products, and people like the artisanal recyclers in Managua, to an extent.

Design Flexibility

Aluminum recycling demonstrates the SCOT idea of design flexibility as many aspects of recycling address a combination of both economic and environmental problems in a symbiotic manner. As newer technologies reduce energy consumption to push down the cost of recycling, the environmental impact also trends down due to the lower energy usage. Furthermore, development of new recycling technologies allowed for higher quality material to be produced through recycling. The higher quality of material allowed for economic incentives to be met while also pushing environmental solutions as the new material could compete with primary aluminum and thus reduce energy use and emissions by replacing traditional mining.

Conflicts

Conflicts between the economic and environmentally focused social groups do arise in a few situations. Namely, quality of finished material often relies on quality of the recycled scrap. This means that low quality scrap is often not worth the effort to recycle as it would involve costly processes to ensure the composition and quality of final material. This conflicts with the goal of reducing the waste generated as recycling companies often discard these materials simply because it is not economically worthwhile. Lastly, a conflict within worker's health occurs as increased safety for recycling workers often clashes with economic incentive and even environmental ones as replacing the recycling with more mining would reduce injury rates.

Closure

Recycling as a technology seems to have mostly rhetorical closure. The technological side of recycling processes mainly focuses on solving the problem with cost and material quality. This can often solve environmental issues as well since the reduction of energy usage reduces both cost and environmental impact. This contributes to the closure of the process. One main point that Bijker and Pinch made about rhetorical closure is that it often occurs through advertisement. Recycling has been well advertised to suit the problems the public seeks to solve as seen through the "reduce reuse recycle" campaign. This further supports the idea that rhetorical closure has been achieved.

Discussion

Through this paper, I have shown that the recycling process as a whole follows closely with the framework described in Bijker and Hugh's social construction of technology. I have identified several social groups affected by aluminum recycling. These include the general public, local communities around mines, recycling companies, manufacturing companies as well as artisanal aluminum forgers. I have described how the problems recycling solves for these social groups can be loosely categorized into environmental and economic problems. This then demonstrates design flexibility as aluminum is a material which recycling can solve the environmental problems alongside accommodating economic incentive. Furthermore, I have identified conflict and closure within the system.

The important point here is how the design flexibility of aluminum does not lead to many conflicts. This allows aluminum recycling to be as successful as it is today, as seen in Figure 4. The ability for aluminum recycling to be incentivized both for environmental impact along with profit maximization leads to a state where the technology can exist comfortably without many further incentives. However, incentives can still be useful and often exist in the form of government policies such as bottle bills to push the environmental benefits of recycling (Quinn, 2023). These government policies can often help increase the coexistence of design flexibility between profit incentivized and environmentally incentivized social groups through increasing profit for recycling.

Moving forward, it is important to use this information to assess the public understanding of not just aluminum recycling but all recycling and remember that in some other cases, the design flexibility does not apply as well. For recycling companies, profit incentivizes aluminum recycling, especially compared to primary methods, but in plastic recycling and other material this often does not apply (Sullivan, 2022). Through looking at our analysis of aluminum we can see that losing economic incentive can result in higher conflict within the process design even while the technology could still obtain rhetorical closure through advertising that makes it seem like plastic recycling is beneficial.

We must analyze recycling technologies as a whole to see whether or not they exhibit the conditions to have design flexibility like aluminum recycling does. This includes recycling for other metals like copper recycling along with papers, cardboard, and various plastics. When they do not exhibit symbiotic design flexibility, further analysis could be done on whether government policies be able to further incentivize their use. This can include monetary incentives like the bottle bill mentioned earlier or even funding to further the technology's development. The analysis of aluminum with SCOT is a good starting point to begin performing further analysis on other recycling technologies to determine the best steps moving forward.

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