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Review

Informing the Public and Educating Students on Plastic Recycling

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Abstract: Approximately 300 million tons of plastic waste is generated per year. The major portion of this plastic waste is landfilled, while part of it leaks into the environment. When plastic waste enters the terrestrial or aqueous environment, it can have negative impacts on ecosystems, human health, and wildlife. Increasing the amount of plastic waste that is recycled will correspondingly reduce the amount of plastic waste that enters the environment. By educating the public and industry on plastic recycling, current recycling programs can be used more efficiently, and new programs can be created. Education material on plastic recycling is available through professional and industry associations, foundations with an environmental focus, university courses, and short courses offered with private companies. This review assembles and analyzes the current education material on plastic recycling that is available from these providers. The material compiled here can be used to gain insight into specific plastic recycling-related topics, to identify areas of recycling education that can be improved, and as a resource to help build university level courses. There is currently a dearth of plastic recycling courses offered at the university level. Educating more students on plastic recycling will equip them with the knowledge and skills to make informed decisions as consumers, and to implement plastic recycling systems at the professional level.

Keywords: recycling; education; waste management; circular economy; sustainability

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1. Plastic Waste and Plastic Recycling

Plastic products are used in large quantities throughout the world (Figure 1) due to their beneficial characteristics: plastic materials are durable, flexible, and low cost. Although there are many benefits of using plastic materials, a major drawback is the amount of waste generated by the manufacturing and use of plastic products. Approximately 300 million tons of plastic waste is generated per year [1]. (Figure 2) Plastic waste cannot be easily broken down in the environment and will persist within landfills and the environment for a long time. Plastic materials can have harmful impacts on the environment and can disrupt ecosystems by having physical and chemical impacts on the health of wildlife [2] and by altering soil structure [3]. Although these negative impacts on the environment are well known, plastic usage continues to grow. The share of plastics in municipal solid waste by mass increased from less than 1% in 1960 to more than 10% by 2005 in middle- and high-income countries [4]. Globally, between 1950 and 2015, the cumulative waste generation of primary and recycled plastic waste is estimated at 6300 Mt, with about 9% being recycled, 12% incinerated, and 78% discarded into landfills or the natural environment [5]. It is estimated that 78% of the plastic pollution problem could be solved by 2040 by using current knowledge and technologies. This would require the implementation of the maximum foreseen application of current pre-consumption and post-consumption solutions. At a 78% reduction in plastic pollution, the durability of plastics will still lead to a large amount of plastic accumulating in landfills and the environment, demonstrating the need to further reduce the amount of plastic pollution [6].

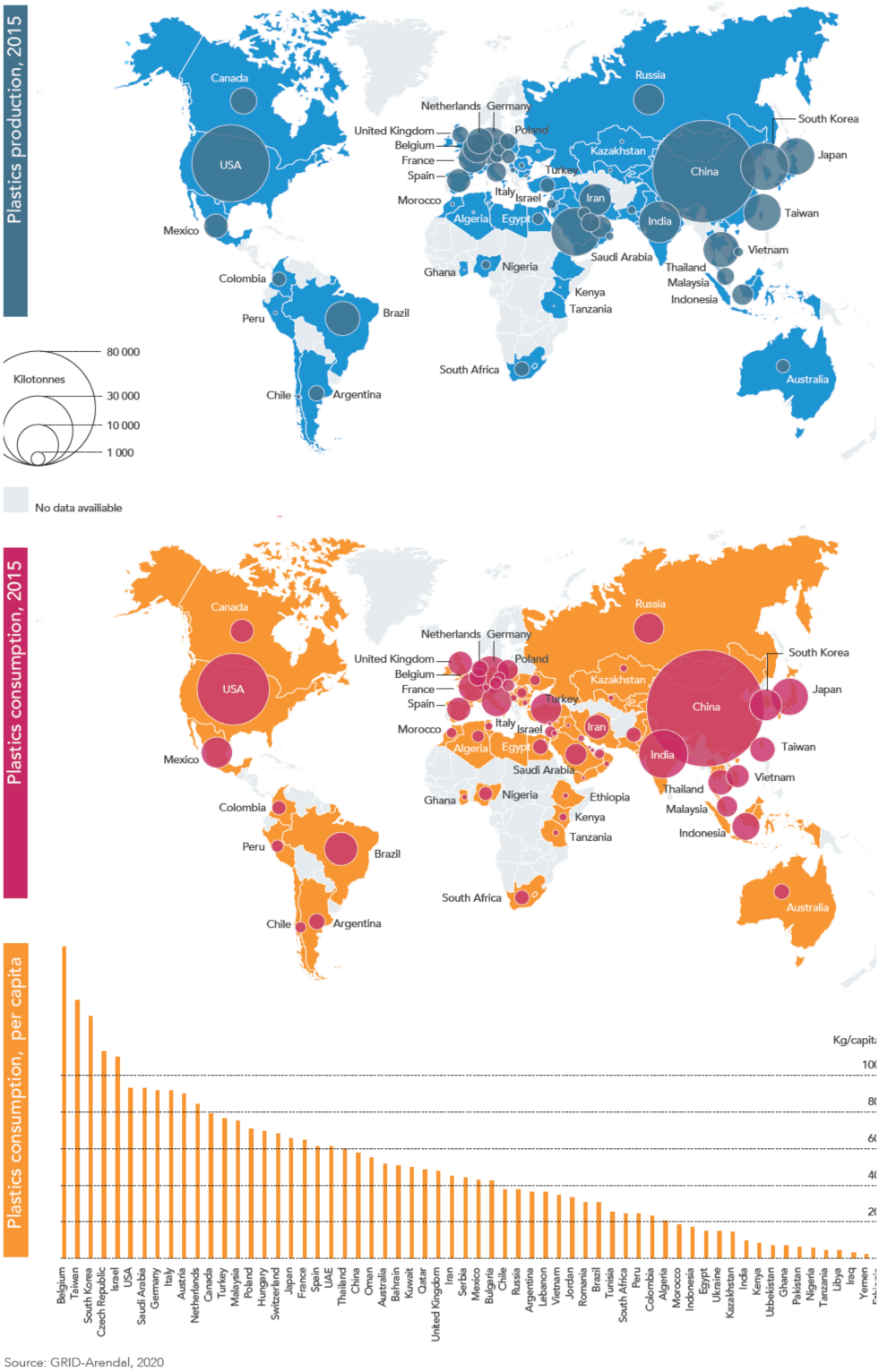

Figure 1. Global plastics production and consumption (source: "Recycling Plastics" report by the Bureau of International Recycling, copyright BIR 2020; reproduced with permission).

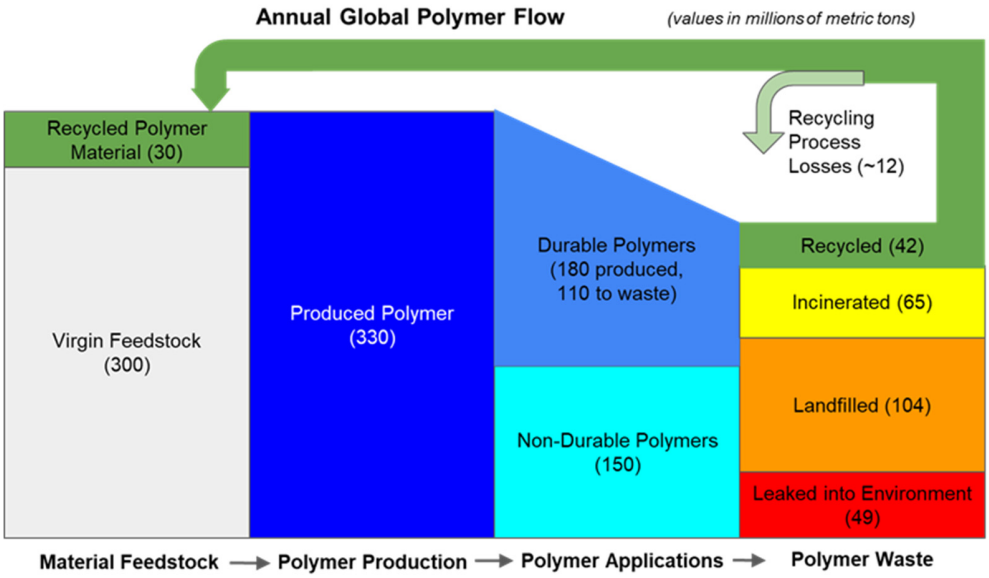

Figure 2. Global polymer flows (millions of metric tons per annum, 2016) showing that the majority of plastic waste ends up landfills and incineration (adapted from "No time to waste: What plastics recycling could offer" 2018 report by McKinsey).

An important way to mitigate the issues caused by plastic waste is to recycle the plastics into new materials, which can reduce the amount of waste that will enter the environment. There are two main methods of plastic recycling, mechanical and chemical. Mechanical recycling uses physical and mechanical processes to sort waste into different types of plastic, and cut the material down into granulates, which can then be reprocessed into new plastic products. Chemical recycling breaks down the polymers into small hydrocarbon molecules which can be used as fuel or processed into specialty chemicals [7]. Mechanical recycling is more common as it is more economically viable and a more developed method. Chemical recycling methods are still being improved upon and the processes involved are becoming more efficient [8].

Current recycling programs include collection and recycling systems for consumers to recycle plastic waste, product manufacturers to recycle plastic waste generated by production processes, and for remediation efforts used in removing plastic waste from the environment. Utilizing these plastic recycling processes will allow for plastic products to continue to be manufactured and used while reducing the amount of waste that will end up in landfills and the environment. Packaging consumes a large fraction (about 40%) of the plastics used world-wide. Approximately 78 million tons of plastic packaging materials are used throughout the world per year. Globally, only 14% of that plastic packaging material is recycled, while 40% is landfilled, 32% leaks into the environment, and 14% is incinerated and/or used for energy recovery [9]. The global non fiber recycling rate has increased at a constant 0.7% per year between 1990 and 2014, and the global non fiber incineration rate has increased at an average of 0.7% per year between 1980 and 2014. If these trends continue, the global recycling rate is expected to reach 44% in 2050 and the global incineration rate to reach 50% by 2050, ultimately reducing the discard rate of non-fiber plastics from 58% in 2014 to 6% in 2050 [5]. To mitigate the issues associated with plastic waste, it is necessary to continue to increase the fraction of plastic waste that is recycled (Figure 3).

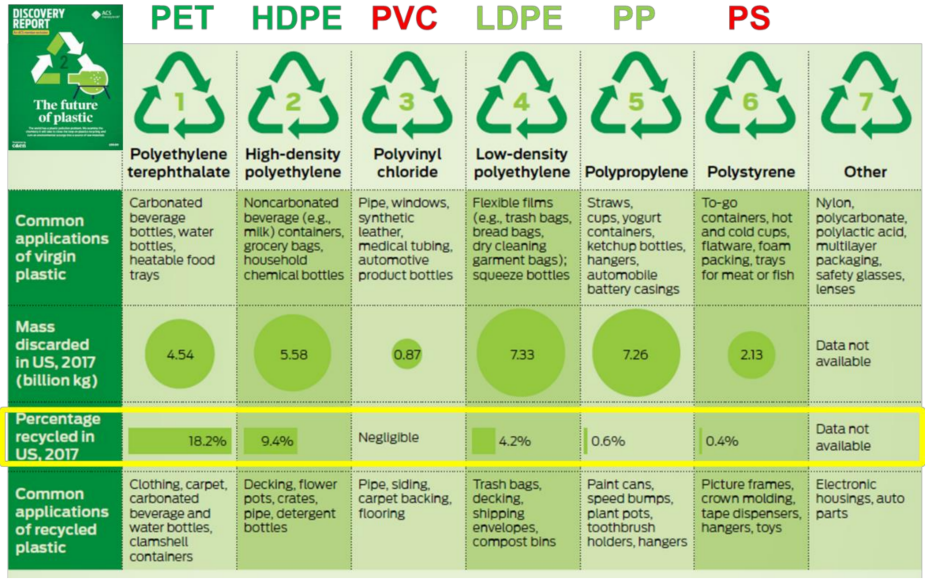

Figure 3. Common types of plastic, mass of plastic discarded in the US (millions of tons, 2017), and percentage recycled in the US (source: "The Future of Plastic" Discovery Report by the American Chemical Society, copyright ACS 2020; reproduced with permission). (Sources of information: American Chemistry Council, Association of Plastic Recyclers, Environmental Protection Agency, More Recycling).

The Recycling Partnership, the largest non-profit organization working towards improving the United States recycling system, has deemed the current US recycling systems as insufficient. A disconnect between plastic product manufacturers, customers, and recycling facilities has contributed to the inadequacy of the current system. It is estimated that less than half of all recyclables in US households are actually recycled. One reason for this is that many consumers are confused by what materials are recyclable or are unaware of how to participate in local recycling programs. Another issue identified within the US recycling systems is that the innovation (and complexity) of plastic-containing products is evolving faster than recycling facilities and systems can manage, hindering the ability of recycling systems to fully capture the material [10].

Educating more people about plastic recycling, including consumers and product manufactures is one way that increased recycling rate can be accomplished. Recycling education is necessary to increase the amount of waste recycled as recycling programs and methods evolve over time and it is important for people to understand how recycling programs operate. Understanding the processes involved with recycling will allow people to fully utilize recycling programs [11]. Studies have shown that recycling education can have behavioral changes, with participants viewing recycling more positively and increasing their participation. This was shown in a study by Askan and Celiker [12] in which teacher candidates were surveyed before and after receiving recycling awareness education. After the education, teacher candidates reported recycling more waste and being aware of the recyclability of the products they purchased. The survey also showed that participants were willing to pay more for products that had a higher degree of recyclability after learning the benefits of recycling. A study by Smith et al. [13] that surveyed elementary school students before and after receiving recycling education, found that recycling education "created a more positive attitude toward recycling and increased the number of recycling behaviors." A study conducted by Chow et al. [14] focused specifically on the impacts of plastic recycling education for primary school students. In this study three different teaching strategies were employed, direct teaching, hands-on teaching, and simulation game-based teaching. The results showed that all three teaching strategies were able to increase the students' knowledge of plastic recycling. The ecological worldview and recycling behaviors did not change significantly for any teaching strategy, but the hands-on and simulation game-based strategies showed an improvement in both ecological worldview and recycling behaviors.

The authors suggest that allocating more time and human resources to the three observed teaching strategies will facilitate significant improvements in the knowledge of plastic recycling, ecological worldview, and recycling behaviors. This recommendation follows the findings of the highly cited report by Hungerford and Valk [15], who concluded that environmental related education is able to change the attitudes and behaviors of students, but not by traditional teaching methods alone. Innovation and supplementing direct teaching with varying teaching strategies is necessary to influence the behavior and attitudes of both citizens and students [15].

The objective of this work is to analyze educational material currently available on plastic recycling, which can be used to provide a framework that can be expanded upon to improve public outreach and education on plastic recycling. This work organizes the different educational material currently available, with each section focusing on a different type of provider, including professional and industry associations, foundations, university undergraduate and graduate courses, and private companies that offer classes on plastic recycling. These different sources offer varying levels of accessibility and can give insight into specific topics within the field of plastic recycling. At the same time, the information compiled here identifies gaps in the plastic recycling education that should be addressed for the benefit of a circular economy. We note that the material surveyed in this report is limited to content available in the English language and is focused on materials providers that are US-based or active in the US.

2. Professional and Industry Associations

Several associations within the plastic manufacturing industry provide educational material on their websites. The educational information provided by these associations typically focuses on specific topics within the plastic material recycling field. This information is beneficial for manufacturers and students to learn more about the processes involved with plastic recycling and the trends within the plastic recycling field. The organizations discussed below are those plastic industry associations that were found to provide educational material that is most relevant to plastic recycling; not all associations that operate within the plastic industry are included. The associations were identified by using an online search utilizing the keywords "association", "plastic recycling" and "polymer recycling". The specific educational material discussed below was identified by searching through the websites of the associations for relevant content.

2.1. American Chemistry Council

The American Chemistry Council (ACC) [16] is a trade association for chemical companies. The Plastics Division [17] of the American Chemistry Council represents the leading manufacturers of plastic resins. ACC publishes a large quantity of material on their website including, but not limited to, infographics and factsheets, reports and studies on the recycling of different plastic materials, and news regarding plastics and recycling. The infographics and facts sheets are the most accessible material and are useful as visual representations and framework for expanding on certain topics such as recycling techniques and the relationship between plastic recycling and the economy. A selection of infosheets most relevant to plastic recycling is discussed below.

"Economic Potential for Advanced Recycling Technologies in the US" [18] utilizes figures and statistics to explain the economic benefits of advanced recycling. This infographic can be supplemented by other infographics that pertain to the relationship between the economy and plastic recycling such as "ACC Plastics Circular Economy Infographic" [19] and "New Investments in Modernizing Plastics Recycling in the US" [20], to explore how plastic recycling and the economy interact. "What is Advanced Recycling" [21] uses figures to provide a basic overview of advanced (chemical) recycling techniques and can be used as a resource along with other advanced recycling infographics to build an understanding of chemical recycling. Related infographics include "Plastics Don't Belong in Our Oceans Advanced Recycling and Recovery Technologies Are Part of the Solution" [22] and "What

are Advanced Recycling Technologies and How Should They be Regulated?" [23]. Other notable infographics and factsheets include "America's Plastics Makers Contribute to Solutions on Marine Litter" [24] which discusses how plastic manufacturers are working towards reducing plastic pollution in oceans, "Plastics Recycling: Two and a Half Decades of Growth and Momentum" [25] which provides statistics regarding the development of plastic recycling over the last 25 years, and "Driving Results for Plastics Recycling Success" [26] which documents how the ACC supports plastic recycling systems.

The reports and studies published by the American Chemistry Council can be useful for gaining insight into more specific plastic materials and different recycling methods. The reports published by the ACC provide statistics and show trends within plastic recycling, such as "The 2019 US Post-Consumer Plastic Recycling Data Summary" [27] which reports the amount of plastic recycled by United States consumers, the "2018 National Post-Consumer Plastic Bag & Film Recycling Report" [28] which reports on the recycling of plastic bags and films, and the "Economic Impact of Advanced Plastics Recycling and Recovery Facilities in the US" [29] which explores the potential economic impact of investments in advanced plastic recycling and recovery facilities.

2.2. Association of Plastic Recyclers

The Association of Plastic Recyclers (APR) [30] is an international trade association that represents companies in the plastic recycling field. The information provided by the APR primarily focuses on the production stage of plastic materials, and the creation of plastic products that can be recycled efficiently. The APR website provides educational material that is useful for both consumers and manufacturers.

Specifically, the APR website contains the APR Plastics Recycling Library [31], which provides accessible material that is designed for consumers to learn about plastic recycling. The Plastics Recycling Glossary [32] posted on the library contains terms associated with plastic recycling and their definitions for consumers to have a better understanding on recycling processes. The library also includes "frequently asked question" documents, which can provide insight into specific topics such as the Degradable Plastics FAQ [33] and the Caps On FAQ [34], which discusses plastic bottle recycling. The Plastic Sorting Best Management Practices [35] provides readers with the information on how to properly sort plastic waste. The Plastics Recycling Library also provides useful website links including links to US legislation on plastic recycling and links to the consumer reports published on the American Chemistry council website.

Notably, the APR provides informative material for manufacturers including a design guide for plastic producers to follow when creating products to ensure their products can be recycled in an effective manner [36]. According to the APR website, "The APR Design® Guide for Plastics Recyclability helps package designers measure each aspect of a package design against industry-accepted criteria to ensure that it is truly recycling compatible". Along with the design guide, APR provides a Training program designed for companies to help create plastic packaging that is recyclable and more sustainable. This material can be used to learn how the recyclability of polymer products is obtained at the production level [36]. The APR hosts a recognition program that celebrates and showcases innovations in plastic packaging design. These innovations and their relevant details are archived on the APR website [37].

2.3. Bureau of International Recycling

The Bureau of International Recycling (BIR) [38] is a global recycling industry association. The BIR website provides an overview of the recycling industry for different recyclable commodities, including an overview of the plastic recycling industry [39]. The overviews provide facts, explain the processes involved in recycling a certain commodity, and discuss the applications for the recycled material. The Bureau of International Recycling publishes "BIR Facts & Figures" [40], which are a series of publications on important recycling data

and statistics for certain commodities over the years. Many of these publications require BIR membership to view.

2.4. Solid Waste Association of North America

Solid Waste Association of North America (SWANA) [41] is an organization that is committed to advancing from solid waste management to resource management through their shared emphasis on education, advocacy and research. SWANA offers occupational training for recycling and waste related fields. The training offered by SWANA includes certification courses, workplace training sessions, self-study courses, and recorded webinars. The courses offered by SWANA are useful for learning about the implementation of recycling programs.

"Managing Recycling Systems Training Course" [42] is an online certification course. This webinar consists of nine online lessons and costs USD 1323 to enroll for non-SWANA members. The Managing Recycling Systems course focuses on recycling materials found in municipal solid waste generated from residential, commercial, and institutional sources. The webinar provides the information to "successfully plan, develop, market, and manage recycling programs, and addresses collection, processing, application of end-use standards, and protection of human health and the environment." The objectives of this course are to allow trainees to be able to:

- Describe the elements associated with designing and developing a sustainable recycling program;
- Determine acceptable material quality and requirements for existing and emerging markets;
- Apply quality requirements and regulatory standards of a "Buy Recycled" program;
- Identify program costs and revenues required to develop funding;
- Establish and manage contracts for recycling services;
- Select the appropriate tools for recyclable collection;
- Plan an education and outreach program.

SWANA also offers single session recorded webinars with a selection of courses. Webinars relevant to plastic recycling include "Blue Approved" Recycling Education: Do You Approve? [43] which involves speakers describing how recycling programs need to evolve and be flexible in order to keep the programs, "I Want To Be Recycled" Campaign [44], which discusses how recycled materials can be utilized and how to support local activation in recycling programs, and Beyond China: Building the Future of Recycling [45] which discusses the domestic recycling programs in China and how the programs need to be improved to be made more efficient. These webinars are useful for gaining insight into the implementation of recycling programs.

2.5. Society of Plastics Engineers

The Society of Plastics Engineers (SPE) [46] is an organization that connects professionals in the plastic industry with the goal of advancing knowledge and education within the plastic field. The SPE website hosts the SPE Library [47] that requires a paid membership to access. SPE hosts educational events and posts the event recordings on their website. These recordings require a fee to view but are offered to students for free. SPE also publishes a quarterly newsletter that provides insight into the plastic recycling industry [48].

SPE produces outreach material through the PlastiVan program [49], which is designed for educating students, teachers, and the general public about the chemistry, history, processing, applications, and environmental issues of plastics. The PlastiVan program consists of trained educators visiting schools and teaching about plastics using demonstrations and hands-on activities. The curriculum taught by PlastiVan educators will vary with the intended age group, with material designed for different age students for grades K-12. The cost for one educator to visit a school or an event is USD 1750 per day. The PlastiVan program also includes PlastiVideo, which allows middle school [50] and high school [51] students to learn about plastics and plastic recycling using online modules. The cost for the PlastiVideo program is USD 1500 for 30-day access. The accessibility (and impact) of

the educational and outreach material offered by the SPE is likely hindered by the required access costs.

2.6. American Chemical Society

The American Chemical Society (ACS) [52] has the goal of supporting scientific inquiry in the field of chemistry. ACS provides educational material on a wide range of chemistry related topics including plastic recycling. ACS publishes news articles that cover developments in the plastic recycling field. These articles are useful to keep updated on the advancements in plastic recycling methods and to identify trends within the plastic recycling field. Examples of news articles include "Rethinking Recycling" [53] and "Companies Bet Big on Chemical Plastic Recycling" [54] which discuss the emergence of chemical recycling. The ACS website also contains educational videos on chemistry related topics, including "How Plastic Recycling Actually Works" [55], which gives an overview of the processes involved in recycling a plastic water bottle.

ACS hosts outreach events and provides educational activities designed for younger students to learn about chemistry related topics such as the impacts of plastic waste and plastic recycling (Figure 4) [56]. The goals of these specific activities are for students to learn about polymer materials, how plastic waste impacts the environment, and the benefits of making environmentally conscious consumer decisions.

Figure 4. Outreach material showing the American Chemical Society mascot (mole) to recycle (source: American Chemical Society, Copyright ACS 2021; reproduced with permission).

3. Foundations and Non-Governmental Organizations

Several foundations and non-governmental organizations provide educational material on plastic recycling. Most of the material provided by foundations and non-governmental organizations is readily accessible and written to be easily understood, making foundations a good source for educational material directed at younger students and consumers. The material provided by foundations and non-governmental organizations is useful for introducing topics related to plastic waste and recycling. Foundations and organizations that provide material on plastic recycling were identified using an online search using keywords "foundation" "plastic recycling", "polymer recycling" and "plastic waste". The foundations and organizations discussed in this report were found to provide material that is relevant to plastic recycling and easily accessible, but not every foundation or organization that deals with plastic recycling is discussed.

3.1. Ellen Macarthur Foundation

The Ellen Macarthur Foundation [57] is a charity that promotes a circular economy. There are articles posted on The Ellen Macarthur Foundation website that discuss plastic recycling and its importance for creating a circular economy. The report "Plastics and the Circular Economy" [58] gives an overview of plastic recycling's role and benefits in creating a circular economy, provides figures, and explains the effects that current recycling methods have on the economy.

3.2. Recycle More Plastic

Recycle More Plastic [59] is an organization with the objective of increasing the recovery of postconsumer plastic. The Recycle More Plastic website contains tools for consumers to learn about and participate in plastic recycling. "Sort for Value" [60] is an interactive tool that enables the user to explore the value of sorting various combinations of plastic bale types. The Sort for Value Tool demonstrates the monetary value in the mixed rigid plastic material. The "Buy Recycled" [61] tool showcases consumer products that are made from recycled plastics, as well as the primary type of post-consumer resin that was used to create the product and the percentage of the product that was made from recycled materials. Recycle More Plastic also provides an interactive case study [62] that uses a diagram to show what steps are involved with recycling, who carries the steps, and how they are done. The "Outreach Builder" [63] tool is used to create outreach material to educate people on recycling programs. The goal of the tool is to assist in educating people about local recycling programs. The website provides definitions for common plastic terms and downloadable images that can be used to create outreach materials or custom flyers that show what can and cannot be recycled by recycling programs.

3.3. Keep America Beautiful

Keep America Beautiful [64] is a nonprofit organization that aims to "end littering, to improve recycling, and to beautify American communities". The Keep America Beautiful website contains information that is educational and useful for both students and consumers to learn about recycling. Keep America Beautiful has published a collection of articles for the different recyclable commodities titled *How To Recycle* that explains what can be recycled, how it can be recycled, and the application for the recycled material. *How To Recycle* [65] content covering plastic recycling include articles focusing on kitchen plastics, plastic containers, and plastic bags. Keep America Beautiful has also published material titled, *The Recycling Journey*, which provides a basic overview for the steps involved in recycling specific products. These articles describe the basic steps a product goes through to become recycled into a new product. One example is the article "Recycling Journey of Plastics" [66], which focuses on the steps for a plastic butter tub to be recycled.

3.4. Upstream Solutions

Upstream Solutions [67] is an organization that educates and works to create "upstream" solutions with a focus on generating less waste rather than dealing with the waste such as recycling and composting. The educational material provided on Upstream Solution's website primarily focuses on reuse of materials. The reuse of plastic materials supplements plastic recycling to reduce plastic waste that enters the environment. The Upstream Solutions website provides articles on the benefits of reusing materials and how reuse products can be introduced into different environments including home, school, and venues [68].

3.5. Plastic Oceans

Plastic Oceans [69] is non-profit organization whose goal is to "end plastic pollution and to foster sustainable communities worldwide". The information published by Plastic Oceans focuses on plastic pollution, including some material on plastic recycling. Plastic Oceans website contains research papers and reports, infographics, news articles, and an

education guide. The research papers [70] and infographics [71] can be useful for showing the importance of plastic recycling to mitigate plastic pollution in the oceans. The news articles on Plastic Oceans primarily discuss plastic pollution, but some articles contain information relevant to plastic recycling such as "Inclusive Recycling: Let's talk About Legislation" [72] and "The Basics On 7 Common Types of Plastic" [73]. The education guide published by Plastic Oceans was created for students as supplementary information to the documentary titled *A Plastic Ocean* [74]. The guide covers information on the impacts on plastic pollution in the oceans, the basics of plastic recycling, and other possible solutions to reducing plastic waste in the oceans.

3.6. Ocean Cleanup

The Ocean Cleanup [75] is a nonprofit engineering environmental organization based in the Netherlands, that develops technology to extract plastic pollution from the oceans and intercept it in rivers before it can reach the ocean. On The Ocean Cleanup website, the processes involved in removing plastics from bodies of water and recycling the removed plastics are detailed. Updates on current projects are also posted on the website. This information gives insight into real world projects that focus on removing plastics from oceans and rivers and recycling the plastic. An article published on The Ocean Cleanup website, "The Plastic Journey Ten Steps to Create a Product from Pollution" [76], gives an overview of the steps involved with removing plastic pollution from bodies of water and recycling it into a new material.

4. Undergraduate and Graduate University Courses

4.1. US Universities

Universities may offer courses at both the undergraduate and graduate level that cover material relevant to plastic recycling. Two subsets of US based universities were surveyed in this review. One subset are universities that offer environmental engineering doctorate programs, and the other universities that offer polymer science or polymer engineering bachelors' and/or masters' programs. Certain universities surveyed were included in both subsets.

The first subset of universities consisted of US based universities that offer an environmental engineering doctorate program. This subset of 93 universities was selected on the basis of their demonstrated commitment on research and education in environmental matters which ought to encompass the management of plastic waste. These universities were identified using findingengineeringschools.org [77] and filtering schools by selecting "environmental engineering". The course catalog of each university that offered an environmental engineering doctorate program was then searched using keywords, "recycling", "plastic", "polymer", or "solid waste". Note that the search covered all university courses and was not limited to courses offered by the environmental engineering programs.

The second subset consisted of US-based universities that offer polymer science and polymer engineering programs, which encompassed 18 universities. The programs surveyed in this subset were found using lists published by universities.com (accessed on 14 October 2021) [78] that compiled US universities that offer plastics/polymer engineering and plastic/polymer technology. Universities that offered bachelor's and/or master's programs focusing on polymer sciences or engineering were included. Universities that only offered associate degrees or technical training were excluded. Courses related to plastic recycling were found by searching the entire course catalog of each selected university that offered a polymer science or engineering undergraduate/graduate program using keywords, "recycling", "plastic", or "polymer".

At the present time, the vast majority of US universities do not offer courses that cover plastic recycling. Relevant courses are offered by only 9 of the 105 universities identified according to the methodology discussed above (Figure 5). Courses that covered plastic recycling material are presented below along with their course description and course content information.

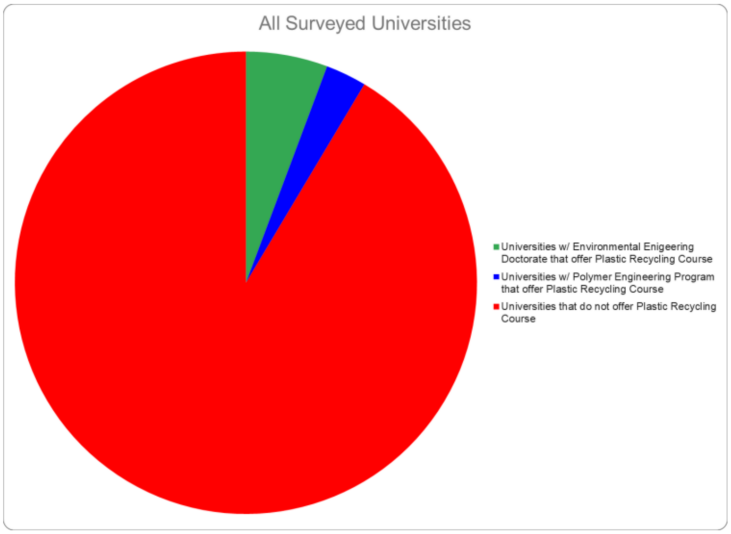

Figure 5. Fraction of US universities offering PhD degrees in environmental engineering and degrees in polymers/plastics which offer courses that pertain to plastic recycling.

4.1.1. Plastics Recycling and Sustainability (EPD639), University of Wisconsin, Madison

Course description: Sustainability and recycling aspects in the life cycles of plastics and polymeric materials. Chemistries that can be used to make polymers from sustainable or renewable sources and biodegradable polymers. Current recycling practices and their limitations including polymer-based materials such as composites and layered packaging. Textile recycling and plastic pollution including microplastics are covered.

Course content information: EPD 639 is a recently offered course and the material is still being developed. The textbook used for this course is *Polymers, the Environment, and Sustainable Development*. Another version of the course is offered as a noncredit, half day seminar.

Offered by: Department of Engineering Professional Development

Contact: Nicole Zacharia, Course Instructor, nzacharia@wisc.edu

4.1.2. Recycling for Sustainability (EN.510.451), Johns Hopkins University

Course description: "I'm so confused . . . which bin do I choose?" Recycling everyday materials and re-using objects made from them have been part of our country's materials-usage landscape for decades. However, as we engineer a sustainable future, recycling will become an ever-increasing component of our strategies for material selection and product design. This course provides an overview of recycling–from the basics of materials recovery, processing and re-use to its economic and environmental impacts. Students will learn about industrial practices associated with recycling and how these relate to our everyday consumer behaviors. Field experiences and laboratory demonstrations will expose students to the realities of recycling. The challenges associated with recycling will be examined to gain a greater understanding of issues related to the use of materials in a sustainable world.

Course content information: The goal of EN.510.451 is for students to gain the knowledge of the science and economics involved with the recycling of different commodities. Topics covered in this course relevant to plastic recycling include PET recovery and processing, polyethylene recovery and processing, and nylon polymer recovery and processing. Two textbooks are used in this course, *Handbook of Recycling* by Worrell and Reuter, and *Understanding Plastics Recycling* by Rudolph, Kiesel and Aumnate.

Offered by: Department of Materials Science & Engineering

Contact: James B Spicer, Course Instructor, spicer@jhu.edu

4.1.3. Sustainable Polymers (9871:350), Akron University

Course description: This undergraduate course introduces students to sustainable plastic technologies, challenges, and the principals of the circular economy. Students will be able to understand how different kinds of plastics are recovered, sorted, and recycled (or not). Topics covered include polymer recycling, composting, bio-based plastics, and life cycle analysis.

Course content information: This course teaches students to identify sources of plastic waste, understand how plastics are sorted for recycling, interpret various resin identification codes and whether plastic materials should be recycled, landfilled, or composted, comprehend the chemical design of sustainable polymers, understand the considerations involved with life cycle assessments, and to apply the principles of a circular plastics economy to product design. The textbook used in this course is *Plastics Fabrication and Recycling* by Chanda and Roy.

Offered by: School of Polymer Science & Polymer Engineering

Contact: Tianbo Liu, tliu@uakron.edu

4.1.4. Recycling of Advanced Engineering Materials (ME 848), Wichita State University

Course description: Introduces the fundamentals of recycling processes, recycling, reprocessing and reusing advanced materials, importance of recycling for the economy, health and environment, and future trends in the field. Focuses on fundamental aspects of advanced materials recycling processes with regard to efficiency of the recycling methods, comparison of the alternative processes, energy usage and efficiency, cost analysis, environmental friendliness (reduction of air, water and soil pollutions), return on investment of recycling factories, characterization, quality and marketability of the recyclates. Graduate students are expected to gain knowledge of fundamental aspects of recycling processes, understanding the separation science and technology, and new techniques developed in the field.

Offered by: Department of Mechanical Engineering

Contact: Eylem Asmatulu, Course Instructor, e.asmatulu@wichita.edu

4.1.5. Recycling of Materials (MATE 476/ENVE 415), Drexel University

Course description: This course will examine the selection criteria for recycling component materials. Recycling involves both reusing materials for energy applications and reprocessing materials into new products.

Course content information: MATE 476 primarily focuses on the recycling and recovery of plastics and metals from electronic materials. The course also covers life cycle assessments and material selection for products. Two Eco-analysis labs are performed as part of this course, where students will track the amount and types of waste produced by a selected group and identify what waste can be recycled. The textbook used is *Materials and the Environment: Eco-informed Material Choice, 2nd edition*, by Michael Ashby.

Offered by: Department of Materials Science and Engineering

Contact: Caroline Schauer, Course Instructor, cls52@drexel.edu

4.1.6. Recycling to Create a Sustainable Environment (SMT-232), North Carolina State University

Course description: The goal of this class is to link the impetus for recycling and recycled materials to the building of a sustainable world. Recycling efficiencies for various materials will be examined as well as recycling practices and attitudes in other parts of the world. This course will explore the technology, economics, markets, trade and social impacts due to the recycling of materials. Case studies will provide an in-depth examination of the problems and potentials for the recycling of selected recycled materials. The use of life cycle analysis (LCA) to evaluate recycling alternatives will be introduced. The economic, policy, social and resource availability drivers for recycling will be examined as well as the technological, economic, market and social barriers to recycling.

Course content information: This course focuses on the recycling of different materials and covers the processes involved with recycling. Students learn about the categorization of waste materials, the economics of recycling, environmental policies regarding waste, and recycling practices throughout the world. Plastic Recycling is also covered as its own topic within the course.

Offered by: Department of Sustainable Materials and Technology

Contact: Ilona Maria Peszlen, Course Instructor, impeszle@ncsu.edu

4.1.7. Design in Solid Waste Treatment Systems (11:117:462), Rutgers University

Course description: Analysis and design of integrated solid waste management systems, including waste minimization, quantity estimates, waste characteristics, life-cycle thinking in waste management, collection, composting and anaerobic digestion, materials recovery, recycling, waste-to-energy, and landfilling.

Course content information: This course explores the systems and processes used to manage solid waste. Topics relevant to plastic recycling are covered such as waste characterization, material recovery facilities design, solid waste legislation, and recycling aspects of solid waste [79].

Offered by: Department of Environmental Sciences

Contact: Uta Krogmann, Course Instructor, krogmann@envsci.rutgers.edu

4.1.8. Processing, Recycling, Management of Solid Wastes (CIEG 436), University of Delaware

Course description: Examines integrated solid waste management systems as well as the regulatory and economic drivers in solid waste management. Employs an engineering perspective in the selection, design, and operation of solid waste management processes including collection, transportation, and landfilling, as well as sustainable options including recycling, composting, and anaerobic digestion. Introduction to principles of life cycle analysis and engineering economics.

Course content information: CIEG 436 discusses waste management and explores options for dealing with waste such as landfilling, recycling, composting, and anaerobic digestion. Recycling is a minor topic covered within the course. Two textbooks are used for this course, *Solid Waste Technology and Management* by T. Christensen and *Waste Management Practices: Municipal Hazardous and Industrial* by J. Pintchel [80].

Offered by: Department of Civil and Environmental Engineering

Contact: Jenny Saxe, Course Instructor, jpsaxe@udel.edu

4.1.9. Solid Waste Engineering and Management (EN.570.490.), Johns Hopkins University

Course description: This course covers advanced engineering and scientific concepts and principles applied to the management of municipal solid waste (MSW) to protect human health and the environment and the conservation of limited resources through resource recovery and recycling of waste material.

Course content information: EN.570.490 focuses on the management of municipal solid waste. Recycling of materials found in municipal solid waste is a minor topic discussed in the course. The textbook used for the course is the *Handbook of Solid Waste Management* [81].

Offered by: Department of Geography and Environmental Engineering

Contact: Hedy Alavi, Course Instructor, alavi@jhu.edu

4.1.10. Plastics & Environment (PLAS.5970), University of Massachusetts, Lowell

Course description: This course investigates the waste management solutions for different types of plastics. Both traditional and emerging recycling methods will be highlighted. Accumulation of plastic waste in the natural environment and the toxicology of plastics as well as their additives will be discussed. Further, analysis methods and instrumentation to characterize recycled plastics, and the differences in virgin polymers and recycled polymers will be introduced. Potential degradable, biodegradable or biobased

alternatives will be reviewed along with the concepts of life cycle assessment and green chemistry for designing the most sustainable plastic materials.

Course content information: This content of this course focuses on processes and trends of plastic recycling and the impacts plastics have on the environment. The objective of this course is to develop students' ability to characterize properties of recycled plastics, investigate, analyze, and optimize a process or a product, design degradable or biobased plastics, perform life cycle assessments, and to use processing machinery, instruments, and analysis software. Textbooks used in this course include *Plastics and environmental sustainability fact and Fiction* by A, Andrady, *Recycling of polymers: Methods, characterization and applications* by R. Francis, *Sustainable plastics: Environmental assessments of biobased biodegradable, and recycled plastics* by J. Greene, and *Introduction to bioplastics engineering* by S. Ashter.

Offered by: Department of Plastic Engineering

Contact: Wan-Ting Chen, Course Instructor, gracewanting_Chen@uml.edu

4.2. International Universities

Dedicated master's degrees in fields related to plastic recycling are offered by international universities. Such universities were identified by searching findingmasters.com (accessed on 14 October 2021) [82] using keywords "plastic", "polymer" or "recycling". Plastic recycling masters programs listed on findiningmasters.com (accessed on 14 October 2021) are discussed below. We note that no US-based universities listed on findingmasters.com offered graduate programs related to plastic recycling.

4.2.1. Master's Program: Resource Recovery-Polymer Materials for Circular Economy, University of Boras, Sweden

The Resource Recovery Polymer Materials for the Circular Economy Master's Program deals with polymer materials and how they can be part of a circular economy. The curriculum includes the recycling and reuse of polymers, biodegradation, and how polymers accumulate in the ecosystem as well as the development of renewable biopolymers and the development of polymers that work in a circular economy [83].

4.2.2. Master's Program: Advanced Materials Innovative Recycling, University of Bordeaux, France

The Advanced Materials Innovative Recycling program allows students to gain expertise in different recyclable materials. The goal of the program is to provide students with the skills and knowledge to develop and implement material recycling systems. The first year of the program focuses on sustainability and general aspects of raw materials. The second year of the programs requires students to specialize in a specific recycling field. The options for specialization include material design for recycling, metallurgy and metals recycling, mineral recycling for construction and other sectors, and the recycling of polymers [84].

4.2.3. Master's Program: Sustainable Science and Technology for Circular Economy, University of Padua (Universta Delgi Studi Di Padova) in Padua, Italy

Program description: The Sustainable Science and Technology for Circular Economy Master's Program is designed to train students for future employment in companies or public bodies applying a circular economy model to production and services. Students are trained on the whole value chain underlying a circular economy model, with a strong focus on techno-scientific skills and competences. The second year of study offers students to choose a "Resources and Product Design and Recycling" study track. This study track allows students to focus on sustainable materials, and recycling including courses that cover plastic recycling material [85].

5. Private Companies That Offer Recycling Education

Several private companies offer courses on plastic recycling for a fee. These courses can range from a single lecture to a multiple week course on polymer recycling or plastic recycling. Courses were identified using an online search for "polymer recycling courses" or "plastic recycling courses". Courses relevant to plastic recycling for which information was readily accessible are discussed below. The courses highlighted here do not represent an exhaustive list of all courses offered by private companies, as there may be other private companies that are not accessible via an online search.

5.1. REMADE Institute

The REMADE Institute [86] is an organization in partnership with manufacturers, universities, and research labs. The REMADE Institute's objective is to reduce the amount of embodied energy and carbon emissions associated with industrial scale production and processing, with the goal of contributing to the reduction of greenhouse gas emissions and increasing both embodied energy efficiency and cross-industry reuse. The REMADE Institute states by "focusing our efforts on addressing knowledge gaps that will eliminate and/or mitigate the technical and economic barriers that prevent greater material recycling, recovery, remanufacturing and reuse." The REMADE Institute offers online workforce training on relevant topics such as plastic recycling, clean energy, and reuse [87]. Plastic recycling courses offered by the REMADE Institute are highlighted below.

5.1.1. Recycling Challenges in a Medium Sized City

This is a 1 h webinar that requires a REMADE Institute membership to access. This course covers the challenges and solutions associated with implementing recycling programs in a medium sized city. The recycling program in Stillwater, Oklahoma is used as a case study [88].

5.1.2. Introduction to Plastics Recycling

This is a 3 h workshop that gives students a better understanding of the most common plastics used today, the recyclable plastics that offer the best economic opportunity, the pros and cons of different recycling methods, the leading government bodies and organizations that working to advance recycling, and the business-assistance programs for recycling implementation in New York State [89].

5.1.3. Crash Course in Plastic Recycling

This is a 2.5 h webinar that requires a REMADE Institute membership to access. In this course, REMADE Institute experts will provide an in-depth overview of existing recycling technologies capable of converting plastic waste into high-value products. Topics covered include washing and sortation protocols, extrusion processes, additives to adjust product properties, and laboratory methods to evaluate feed materials and products. This course is designed for newcomers to the field of plastics recycling and for industry veterans to strengthen their knowledge on the basics of plastic recycling [90].

5.1.4. Plastic Waste Valorization for a Circular Economy: Perspective on Chemical Recycling

This is a 1 h webinar that requires a REMADE Institute membership to access. The course discusses the bottleneck of conventional plastic recycling, state-of-the-art emerging chemical recycling methods including pyrolysis, chemolysis, and hydrothermal processes, and case studies about using chemical recycling to reuse the end-of-life waste [91].

5.1.5. The Technology of Plastic Recycling

This is a 1 h webinar that requires a REMADE Institute membership to access. This course discussed the technologies available to recycle waste plastics, reviews existing and emerging technologies available for cleaning, separating, purifying and compounding these waste plastics into high quality pellets suitable for use in new products, addresses

the limitations of mechanical recycling and identifies areas where chemical recycling might be viable options [92].

5.1.6. Flexible Plastic Packaging: Industrial Landscape Challenges and Opportunities

This is a 1 h webinar that requires a REMADE Institute membership to access. This course covers the composition and structure of typical flexible packaging types, discusses current options for recycling these materials, and shares recent results from REMADE-funded work on this topic [93].

5.2. Udemy

Udemy, Inc. is a massive open online course (MOOC) provider aimed at professional adults and students. Udemy provides courses on many different topics, including courses on polymers and recycling.

Plastic Recycling: A Beginner Course

This is a single session 90 min online course that costs USD 20 to enroll. This course covers the topic of plastic recycling with the aim of equipping participants with a fundamental knowledge of how this is done. The course begins with an overview of the global plastic challenge and then goes on to explain the processes involved and the mechanisms behind some of these processes. A bench-scale recycling process is included for the purpose of demonstration. The learning outcomes of this course include: how to identify the common types of plastics, the global plastic challenge and impact, the recycling process and mechanisms, practical demonstration of a bench scale recycling process, and the advantages and challenges of large scale and small scale recycling [94].

5.3. Omnexus

Omnexus is a global, neutral online marketplace focused on delivering products and related services to the plastics industry. It provides a single point of connectivity for plastics processors and suppliers. The Omnexus website offers live courses, on-demand recorded courses, and video tutorials.

5.3.1. Chemical Recycling of Plastic Waste: Basis, Technologies & Advances

This is a live online 90 min course that costs USD 355. This course is designed for recyclers, manufacturers, and suppliers that are interested in introducing chemical recycling. The material covered includes the basis of chemical recycling, chemical vs. mechanical recycling, pyrolysis, solvolysis, enzymatic depolymerization, and future perspectives in chemical recycling [95].

5.3.2. Plastic Recycling Innovation: Materials, Technologies, Applications Update

This is a live online 90 min course that costs USD 355. This course is designed for plastic resin, compounder, and additive suppliers in conjunction with their major end users, brand owners and customers. The material covered includes advanced plastics recycling overview, material advances, technologies, application, and major innovations, the future of advanced plastics recycling, and major advanced plastics recycling players/references [96].

5.4. ICIS (Independent Commodity Intelligence Services)

ICIS is a private company that connects data, markets and customers to create a comprehensive trusted view of global commodities markets. The ICIS website offers virtual training and webinars on chemical and energy related topics.

Virtual Training—An Introduction to Plastics Recycling

This is a 4-day course that costs USD 1000 to enroll. The goal of the training is to deepen the attendees' understanding of the recycling business–from chemical recycling and waste management to market dynamics across polymers. The key topics include the

different types of polymers, future trends of polymers, polymer market dynamics, future challenges of recycling technologies, the relation between end markets and the evolution of plastics recycling, and the impact of the refocus on design for recycled products [97].

6. International Plastic Recycling Education

This report focuses on plastic recycling education material that is available in the United States, but other countries throughout the world have education programs for their citizens to learn about plastic recycling. Some examples of recycling education offered in other countries are highlighted below, but this is not an exhaustive list of countries that promote recycling education.

In Japan, communities promote and provide guidance for recycling through the regular publication of guidebooks and magazines including the door-to-door distributed *Guidebook for Sorting Recyclables and Waste*. Japanese recycling collection systems require plastics to be sorted into specific containers for different polymer materials, which requires citizens to be more directly engaged with their waste collection system [14].

In Taiwan, the Environmental Education Act requires all students and staff in government and business to engage with at least four hours of environmental education every year [98]. There is also the "Four-in-One program" that works to connect the collaboration of four different stakeholders, including community residents, recyclers and collectors, local governments, and the local recycling fund, to collect regulated recyclable waste, with the goal of increasing the citizens' engagement with recycling [14].

The Hong Kong government published a teacher's guidebook called *Reduce Your Waste and Recycle Your Plastics* and created "Reduce Your Waste and Recycle Your Plastics Campaign" in which the participating schools encouraged their students to clean and remove labels from plastic bottles and put them in recycling bins at their school. The teacher's guidebook and the campaign aimed to provide students with the knowledge of waste management and achieve behavioral change on waste reduction and recycling [14].

The government in Ghana launched the Nationwide Waste Education Campaign, which aims to teach waste management to 81,000 students by 2022. The campaign also provides recycling facilities in schools and aims to instill a culture of waste reduction in the younger generation of students [98].

In Malaysia, the Smart Ranger program works to engage students with natural resource management, beginning with recycling. The program also included a trial of a buyback program for recyclable wastes to incentivize recycling [98].

Germany has had success in gaining participation in plastic recycling from both manufacturers and consumers. State level and local level governments sent out brochures and pamphlets to citizens that educate about all processes involved in solid waste management systems such that the community understands how the systems work and how to participate properly. German waste collection systems require sorting of different materials into color coded containers at the source. The German government has also created economic incentives for recycling, including fines for improper sorting, deposits on beverage containers that are repaid when recycled, and weight-based collection fees for disposing waste [99]. Manufacturers are encouraged to be educated on recycling and waste reduction due to the widely used Green Dot system, which was first adopted in Germany. The Green Dot System requires manufacturers to pay a financial contribution to an approved recovery organization to cover the cost associated with recycling the packaging of their product. The Green Dot System or similar systems are currently implemented in 32 European countries [100].

7. Conclusions

Plastics are materials extremely valuable to our society and are widely used across industries such as food, beverage, textile, automotive, aerospace, construction, agriculture, healthcare, and petroleum. The low density, water resistance, and mold-ability of plastics render plastic packaging crucial for food safety, storage, and distribution [101].

The use of polymers as electrical insulators enabled the transportation of electrical energy. Polymer membranes are used for water desalination, fuel cells, and batteries. Healthcare applications of polymers extend to drug delivery, implants, and medical devices [101]. The critical importance of plastics is currently evident in their widespread use in personal protection equipment against coronavirus [102]. Plastics are also important in helping meet the United Nation's Sustainable Development Goals (SDGs) [103], but as the world population increases, and as people living in developing countries improve their living standards to the level of industrialized countries, the demand for plastics will continue to rise and is projected to exceed 1 billion tons/year in about 50 years [101]. More plastic consumed means more plastic ending up in waste. The major portion of plastic waste is landfilled, while part of it leaks into the environment. An important way to mitigate the issues caused with plastic waste is to recycle plastics.

The educational material discussed here is useful in building a framework and creating a basic overview of plastic recycling. Educational material on plastic recycling is available from a range of different providers. The different sources of educational material on plastic recycling focus on specific topics within the plastic recycling field and provide varying levels of accessibility. The usefulness of the material will depend on the role and the prior knowledge of the audience. Consumers can use the material highlighted here to learn about the systems involved with plastic recycling, which will allow for increased participation in recycling programs and provide the consumer with the knowledge to make informed decisions. Manufacturers can use this material to produce products that are recyclable and to track trends within plastic markets. Industry professionals can use this material to stay up to date on the developments within the plastic recycling field. The educational material provided by associations that operate in the plastic recycling industry is most beneficial for manufacturers looking to implement processes or products that promote recycling and to keep updated and informed about the industry. Material provided by associations is also useful for students and consumers to gain insight into the plastic recycling industry. Material provided by environmentally focused foundations is ideal for students and consumers who are looking to learn the basics of plastic recycling. Material provided by foundations also helps consumers to learn how to participate in recycling programs and make informed decisions when buying plastic products. Universities that offer plastic recycling courses allow students to learn about different topics within the plastic recycling field and can be later applied in their professional field. Plastic recycling courses offered by private companies are useful for industry professionals to learn the basics of plastic recycling or to learn about specific topics within the recycling industry. However, the course fees make such courses less accessible to students and the general public.

While useful educational material is available, more outreach and plastic recycling education is necessary to contribute to the mitigation of the issues created by plastic waste. The lack of educational material is evident at the university level, as only 8.6% of the United States-based major universities with doctoral programs in environmental engineering or graduate programs in polymers offer courses that include content on plastic recycling. Increasing the number and variety of university courses will help inform more students about the processes and benefits involved with plastic recycling. Offering plastic recycling courses at the university level can provide students with the skills and knowledge to implement recycling systems at the professional level and will give them the knowledge to make informed consumer decisions, which can contribute to an increase in the percentage of recycled plastic, ultimately reducing the amount of plastic waste that enters the environment.

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