WRITTEN TESTIMONY OF:

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Introduction

I would like to thank Chairman Tonko, and the rest of the Environment and Climate Change Subcommittee for the opportunity to testify at this hearing to address solid waste management. It is an honor and privilege to be with you today. My name is Jenna Jambeck and I am a Distinguished Professor of Environmental Engineering at the University of Georgia and a National Geographic Fellow. I have been conducting research on solid waste issues for 24 years with related projects on marine debris since 2001, including research on reuse, recycling and life cycle assessment of solid waste management options. I have also sampled open ocean plastic sailing across the Atlantic and co-developed the mobile app, Marine Debris Tracker, funded by the NOAA Marine Debris Program. I have presented at three Capitol Hill staffer briefings, a Global Ocean Commission meeting, the 2015 Our Ocean Conference, G7 and G20 Meetings, the United Nations, and at the White House Office of Science Technology and Policy (OSTP). I also serve as the U.S. representative on an Advisory Panel for the United Nations Environment Program Global Partnership on Marine Litter. I testified on May 17, 2016 to the Senate Subcommittee on Fisheries, Water and Wildlife and to the House Subcommittee on Water, Oceans and Wildlife October 29, 2019 on similar topics. I have participated in the International Informational Speakers Program with the US State Department since 2017 and have been to thirteen different countries/economies working on the issue of marine debris and plastic waste in public environmental diplomacy (Chile, Philippines, Indonesia, Japan, South Africa, Vietnam, Jordan, Israel, South Korea, India, Bulgaria, Taiwan, and China). My testimony today is my opinion, based upon my background and experience in studying solid waste, plastic and marine debris.

Key Points

Based upon my research and written testimony, I recommend that Congress can best support solid waste management while protecting human health and the environment in the United States by:

1. ***Better data collection and tracking of materials.***
    a. Data in waste collection has been historically variable. Because regulatory implementation was given to the states, it created a supportive context-sensitive environment, but it also produced a diversity of, for example, terms, definitions for recycling, and collection and management systems. This variety has led to a loss in

efficiency and economy of scale, and sometimes incomparable data across communities and states.

b. In addition, all materials, but especially plastic, should be better tracked – both as a mass of material used and a quantity of items produced. This tracking would help ensure the collection and capture of items and materials for their highest level of management.

2. ***Reducing waste generation.***

   a. Environmentally speaking (e.g., water and energy use, GHG emissions), it is best to not produce any waste to manage at all, and as a country, we generate the most waste in the world. Congress could support legislation to reduce waste generation, encourage business innovation and alternative product delivery models <u>that don't produce waste</u> (count and mass metrics are both important here). Support legislation that allows reuse models to be implemented more easily.
   b. This could mean considering phasing out some of the most problematic materials (that negatively impact our waste management systems or the environment), products, or putting fees on items. In addition, other countries have seen waste generation decrease when waste reduction is incentivized through cost.
   c. Incentivize innovation and business that promotes reuse instead of waste generation, and quantify these waste offsets (e.g., mobile dishwashing, reusable cup systems, etc.).

3. ***Promoting high value materials and product designs that are easy to capture and recycle.***

   a. Being thoughtful about the materials we use and the design of our products and packing are essential to increasing capture and recycling rates. If a material itself is not of high enough value to promote recapture, then a deposit-return schemes may be needed to incentivize collection (deposit-return schemes show a 40% reduction in litter from beverage containers where in place in the USA).
   b. Product stewardship/extended responsibility initiatives can do several positive things like provide resources for the collection and management of waste (primarily the responsibility of communities and citizens right now), incentivize more consistent design of packaging and material usage to retain value, and stimulate the economy with more domestic recycling business opportunities.
   c. If high value materials are used, and domestic markets are developed (per a and b above) the export of recyclables will not be as necessary and can be reduced. In addition, if export is needed, then the materials will be cleaner and of higher value as a commodity to others promoting positive global trade (especially if the USA helps countries develop context-sensitive solid waste management systems globally).

4. ***Consider source separating organic (e.g., food waste) and other materials.***

   a. Food waste is beginning to be addressed more actively in the USA, source separating it will reduce GHG emissions from solid waste management systems (especially landfills).

b. Although the USA has moved to single-stream recycling, while waiting for product design changes to happen (which are more long term), more source separation or secondary source separation may be needed for cleaner commodities, or to at least remove contaminants from the waste and recycle stream. This could include campaigns related to capturing lithium-ion batteries or separating out some of the most valuable recyclables for individual home collection with varying frequency.

5. ***Community-based data collection and citizen science.***
    a. With proper frameworks and structure, citizens can contribute to critical data needed to inform circular materials management in communities on the front lines of waste management. In addition technology like RFID, artificial intelligence and eco-feedback can add to data collection.
    b. People should know their own waste. Out of sight has been out of mind, but we can't get to a circular economy at the community level if people don't think about and understand waste. Participating in community data collection, "peeking behind the curtain" in solid waste management (even if virtually), can help people to become more aware. In many cases, people already *want* to help and make a difference (plastics and recycling are very salient issues), but they don't know what actions to take.
    c. Acknowledging solid waste management systems and workers at the front lines for their efforts to manage as best they can the waste that we all produce every day. How do we change the perception of "gross and dirty" to valuable materials that we can be proud to capture?
    d. <u>We need leadership from corporations and government</u>***.*** If corporations and governments are more thoughtful about products, materials and waste, citizens will be too.

Context

I think it is important to provide context and introduction similar to when I gave other testimony in 2016 and 2019, the US regulatory history is always relevant. I grew up in the 1970s outside a small town (fewer than 3,000 people) in Minnesota. Like many people at the time, we managed our trash by taking it to the landfill and putting it in ourselves. I always found it fascinating to see what people throw away – and I have seen bowling balls to bologna in landfills. In graduate school, my fascination turned into a passion for studying solid waste management as an environmental engineer. Environmental engineers can also design urban drinking water and wastewater facilities, but to me, solid waste management felt like it most closely involved people. Unlike the small effort required to turn off a faucet or flush a toilet (even a sensor can do this with no human effort), we all have to decide daily what to consume, what materials to use, what *is* and *is not* "solid waste" in our own home, and then whether to give away, discard, compost or recycle unwanted materials. The human component of solid waste management, and the direct interaction with people, is an aspect of my research that continues to be essential to my work.

In 1976 Congress passed the Resource Conservation and Recovery Act (RCRA) that required the U.S. EPA (typically through the states) to regulate solid and hazardous waste. [1] "Open dumping" was prohibited and replaced by engineered and regulated landfills, composting and recovery systems.[2] RCRA also specifically called for research to inform solutions, including demonstrations and special studies on measures to reduce the generation of waste, waste collection practices, and economic incentives to promote recycling and waste reduction (among other things).[3] Because of RCRA, we had outstanding progress in solid waste management, just in my lifetime. However, solid waste management has remained a complex issue, and for a multitude of reasons, especially historical mismanagement, no citizen wants it anywhere near them, but then waste ends up being managed only where people don't have the capacity to fight it, creating a long-standing environmental justice issue.

Global Plastic Production and Waste

Globally, 2.01 billion metric tons of waste is generated annually[4]. Plastics completely changed our world after their expanded use in World War II, and global annual plastic production has increased from 1.7 million metric tons/yr in 1950 to 360 million metric tons/yr (not including polyester fibers) in 2019.[5] Along with a steep increase in production, we have seen a resulting increase in plastic in the waste stream from 0.4% in 1960 to 13.2% in 2017[6] (by mass) in the U.S. All traditional plastics do not biodegrade, but only fragment into smaller, ultimately microscopic or nanoscopic, pieces.

A cumulative 8.3 billion metric tons of plastic has been produced since 1950[7]. Since approximately 40% of plastic is used for packaging and single use items, this means that 6.4 billion metric tons has become waste by 2015 (Figure 1)[6]. Globally, on average, we have recycled only about 9% of plastic, with 12% recycled and 79% ending up in our landfills or in the environment. With cumulative quantities projected to reach 34 billion metric tons of production and 12 billion metric tons of waste, the management of plastic in the waste stream is only continuing to grow.[6]

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[1] Resource Conservation and Recovery Act (RCRA) - Public Law 94-580, October 21, 1976, (42 U.S.C. 6901-6992; 90 Stat. 2795), as amended by P.L. 95-609 (92 Stat. 3081), P.L. 96-463 (94 Stat. 2055), P.L. 96-482 (94 Stat. 2334), P.L. 98-616 (98 Stat. 3224), P.L. 99-339 (100 Stat. 654), P.L. 99-499 (100 Stat. 1696), P.L. 100-556 (102 Stat. 2779)

[2] Code of Federal Regulations (CFR) Title 40, Parts 239 – 282

[3] https://www.epa.gov/aboutepa/new-law-control-hazardous-wastes-end-open-dumping-promote-conservation-resources

[4] http://datatopics.worldbank.org/what-a-waste/

[5] Plastics Europe, https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts2019_14102019.pdf

[6] https://www.epa.gov/sites/production/files/2019-11/documents/2017_facts_and_figures_fact_sheet_final.pdf

[7] Geyer, R., Jambeck, J.R., Lavender Law, K. (2017). Production, use, and fate of all plastics ever made, Science Advances, 19 Jul 2017, Vol. 3, no. 7

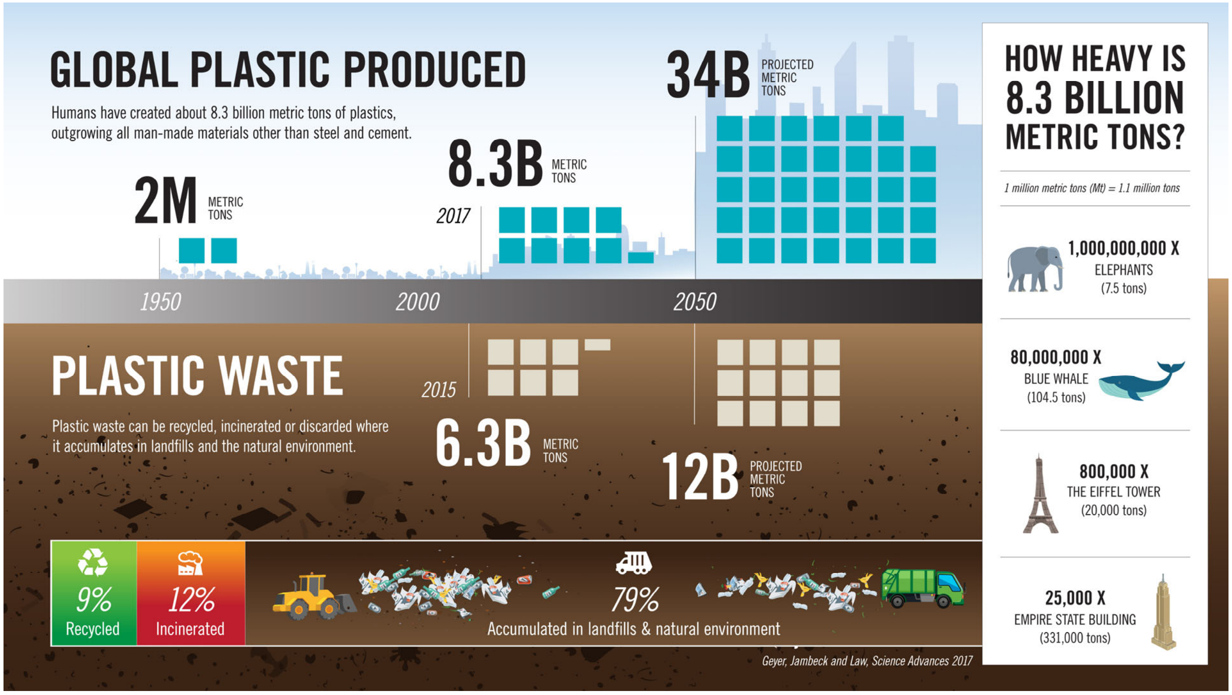

Figure 1. Global Materials Flow of Plastic[6]

Waste and Plastic in the USA

In the USA, the per person waste generation rate ranges from 4.5 to 6 lbs/person/day, depending on the reference examined[8]. This is 2-6 times the waste generation rates of many countries around the world[9]. While the USA is the third most populous country in the world, we still only have 4.3% of the world's population, but we are the top waste producer of waste, 16.4% of the world's waste stream currently about 329 MMT of waste annually. The reality is, we cannot be 'saved' by recycling as it is now – our recycling rates have never risen above a third of our waste and we are currently at 25%. We landfill 52% of our waste, compost 10% and combust 13% in the US[10].

The recycle rate is driven by high value items, like cardboard and paper (66%) and metals (33%) with plastics being one of the least recycled materials of all (8.4%). The recycling percentage for all plastic in the USA is slightly less than the global average, although rates for individual polymers vary (Table 1)[11]. While the polymers that make up the plastics that we commonly encounter are listed in Table 1, plastics also contain additives to alter color, texture, shape, form, antimicrobial surfaces, make it flame retardant, and for other properties.[12] The wide variety of available additives results in thousands of different plastic material compounds for particular purposes, creating a diverse array of plastic materials

[8] https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials#Generation; https://erefdn.org/national-waste-generation-recovery-and-disposal-assessment/
[9] http://datatopics.worldbank.org/what-a-waste/
[10] https://www.epa.gov/sites/production/files/2019-11/documents/2017_facts_and_figures_fact_sheet_final.pdf
[11] https://www.epa.gov/sites/production/files/2018-07/documents/smm_2015_tables_and_figures_07252018_fnl_508_0.pdf
[12] Additives have been mixed into plastic compounds since they have been in the consumer market: Deanin, R.D. (1975). Additives in plastics, *Environmental Health Perspectives*, 11: 35-39.

that end up in our trash, which can make recovery and recycling challenging. Table 2 contains the items that get recycled at the highest rates in the US, along with potential reasons on why these items have relatively high recycling rates. While HDPE (natural only) and PET are both polymers on the list, the rates are not over 32% recycling rate for these, which is still relatively low, but they are the two most recycled plastic items at these low rates. What do the items have in common? In some cases, there are legislation, in others, there is more source separation keeping the material cleaner with higher value, in other cases the material simply has an inherent higher value. Maybe there are some commonalities to learn from in working to improve our infrastructure and recycling rates in the US.

Table 1. Common Materials and Polymers, USA Recycle Rates for Containers (total is usually less)

Polymer	**Recycling Number**	**Common Use(s)**	**Recycle Rate**
Polyethylene Terephthalate (PET)	1	Individual beverage bottles, textiles	18.5%
High Density Polyethylene (HDPE)	2	Gallon jugs, some personal care product and detergent bottles	10.3%
Polyvinyl Chloride (PVC)	3	Piping, siding (construction)	Negligible
Low Density Polyethylene	4	Retail bags, thin film plastic	6.1%
Polypropylene	5	Bottle caps, yogurt containers, toys	1.0%
Polystyrene	6	Foamed/expanded PS in packaging	1.3%
Others	7	Fishing nets (nylon), carpet	23.4%

Table 2. Highly Recycled Items in the USA and Potential Reasons Why

Item	**Recycle Rate**	**Why do people recycle / materials get recycled?**
Lead-Acid Batteries	99.1%	Required to be collected and recycled by legislation
Cardboard	88.4%	High value item, homogenized material, sometimes collected separately
Steel Cans	70.9%	Easily separated accurately with magnet at materials recycling facilities, heavy, homogenized material
Aluminum Cans	49.2%	Some deposit-return schemes, homogenized material, eddy-current separator
Tires	39.9%	Regulated, restricted from landfills
Some Electronics	35.9%	Valued items, collection centers/days, store take-back, source separated
Glass	33.9%	Glass does not have much value, but has mass, which may contribute to recycling
HDPE Natural (subset of total)	31.2%	Because it is higher value, natural in color, and heavier, easy to see/separate by hand, e.g., milk jugs
PET (Bottles and Jars)	29.1%	Most of them clear, heavier, higher value, fairly easy to manually separate

In terms of climate change and greenhouse gas emissions, landfills are reported to contribute 16% of U.S. methane emissions and are the third-largest nationwide source of that greenhouse gas.[13] Methane is generated from the organic materials biodegrading in the landfill. While yard waste is often regulated and restricted from landfills (69.4% then composted), food waste is not. Only 6.3% of food waste is composted in the US, with the rest going to landfill. Separating out/managing food waste separately could have a positive cascade impact on US infrastructure. While likely expensive to develop, food waste composting or anaerobic digestion could reduce GHG emissions (as long as transportation is not increased), keep the rest of the waste stream cleaner and potentially easier to manage. While not just related to plastic, an integrated waste management approach is needed to move closer to circular materials management and reduce impacts to climate change. The US EPA's WARM model estimates impacts from recycling and composting materials from the waste stream and overall the benefits to recycling are like taking 39 million cars off the road per year, which is significant[14]. However, for individual items, plastic is the highest non-GHG reduction item, with recycling estimated to be like putting 810,000 cars back on the road[14] (although the 39 million is already a net value).

Import-Export of Plastic Waste

While recycling and the circular economy have been touted as potential solutions to this issue, one can see from the recycling percentages given in the previous sections, we have a long way to go for recycling to be significant. Approximately half of the plastic waste intended for recycling has been exported to hundreds of countries around the world (Figure 2). Before their import restrictions (resulting really in a ban) in 2017, China had imported a cumulative 45% of plastic waste since 1992[15]. Compiled commodity trade data by Amy Brooks in my research group illustrated that higher-income countries in the Organization for Economic Cooperation (OECD) have been exporting plastic waste (70% in 2016) to lower-income countries in the East Asia and Pacific for decades[33]. An estimated 111 million metric tons of plastic waste is displaced with the new Chinese policy by 2030[33] begging the question of where this plastic goes now and will continue to go – and causing one of the biggest economic disruptions to recycling ever to happen in the USA. With 89% of historical exports consist of polymer groups often used in single-use plastic food packaging (polyethylene, polypropylene, and polyethylene terephthalate), bold global ideas and actions for reducing quantities of nonrecyclable materials, redesigning products, and funding domestic plastic waste management are needed[33]. The USA and others who have exported to countries that lack waste management systems are responsible for some of this mismanagement. In China alone, this added another 11% of plastic mass to their waste stream to manage in 2015[33]. Rethinking trade agreements and the balance of resources to be able to participate in trade for countries (like small island sates) that need to, is important. This is also a large global economic system that involves the livelihood of millions of people around the world. Improving their conditions and protecting the environment should be paramount. New amendments to the Basel Convention have put

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[13] https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane

[14] https://www.epa.gov/sites/production/files/2019-11/documents/2017_facts_and_figures_fact_sheet_final.pdf

[15] Brooks, A., Wang, S. Jambeck, J. (2018). The Chinese import ban and its impact on global plastic waste trade, Science Advances, 20 Jun 2018: Vol. 4, no. 6, DOI: 10.1126/sciadv.aat0131

requirements on exporting countries to at least notify and get consent for shipments[16]. The USA could help lead efforts to both improve and develop domestic infrastructure while participating in responsible global trade of recycled materials.

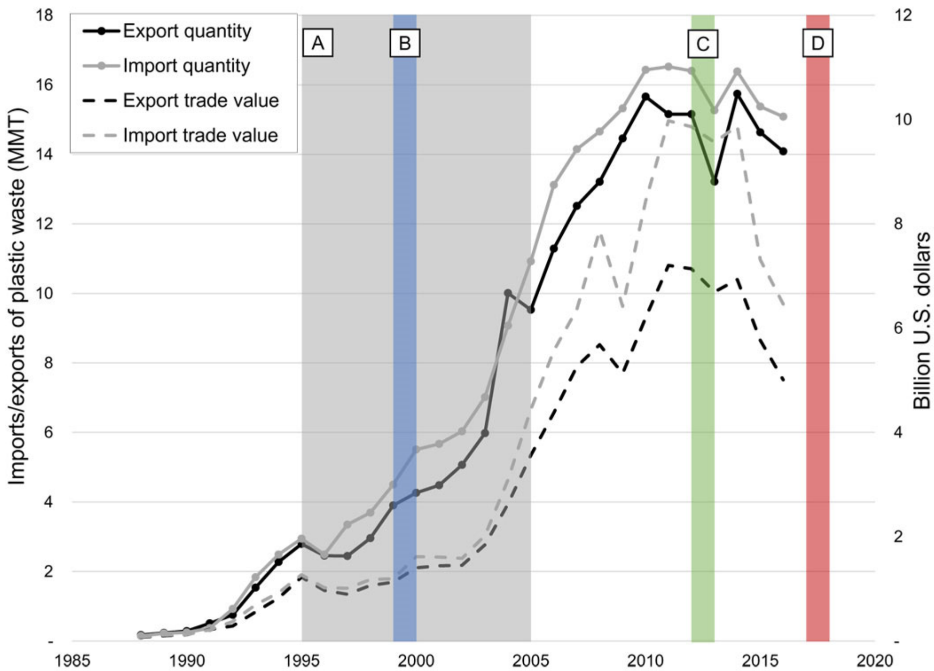

Figure 2. Trade of plastic waste in mass and trade value (UN Comtrade data)[33] (Notes: A = single stream recycling, B = WTO encouragement of global trade, C = "Green Fence", D = "National Sword")

Input into the Ocean from Mismanaged Plastic Waste

While this report discusses all waste, there is a specific focus on plastic so our estimate of mismanaged municipal plastic waste entering the oceans is shared here. In 2010, we estimate that 275 million metric tons (MMT) of plastic waste was generated in 192 countries. Of that, 99.5 MMT of this waste was generated within 50km of the coastline, and 31.9 MMT was mismanaged. We then estimated that between 4.8 and 12.7 MMT (a mid-scenario of 8 MMT) reached the oceans[17] (Figure 3). This annual input of plastic is equal to 5 grocery-size bags filled with plastic going into the ocean along every foot of coastline in the world. The U.S. is one high income country on the list, and while our waste management systems are well-designed and very effective, and the only mismanaged waste is from litter, we have a large coastal population and a large waste generation rate. If we look to the future, and assume a business as usual projection with growing populations, increasing plastic consumption and increased waste generation, but no increase in capture of waste, by 2025, the 8 million metric tons doubles – with a cumulative input by 2025 of 155 million metric tons.

[16] http://www.basel.int/Implementation/Plasticwastes/Overview/tabid/6068/Default.aspx

[17] Jambeck, J.R., Andrady, A., Geyer, R., Narayan, R., Perryman, M., Siegler, T., Wilcox, C., Lavender Law, K., (2015). Plastic waste inputs from land into the ocean, Science, 347, p. 768-771.

Figure 3. Plastic Waste Inputs from Land into the Ocean in 2010

Interventions and Mitigation Strategies

I developed the framework in Figure 4 for my 2016 testimony[18] on plastics in the ocean, while this is a solid waste hearing, some of these interventions are just as relative for solid waste management in general. I submit this now with a more refined focus on solid waste management, including upstream interventions that reduce waste we generate in the first place. This framework provides action points (1 through 5) and then a list of potential (but not all encompassing) interventions that may occur at the various points. In general, this represents a hierarchy. However, the most "bang for your buck" interventions will depend on the needs of the specific geography addressing the issue, and, in many cases, all geographies have points along the entire framework that will help reduce and manage waste. Some interventions can be immediate, and some will take more time. The framework starts on the left with the most "upstream" interventions and ends with a characterization of what ends up on the ground. <u>In many cases the interventions offer the opportunity for economic innovation and growth.</u>

[18] https://www.epw.senate.gov/public/_cache/files/8/0/8074ded1-5986-4a9b-b033-2eb69e66993f/B775115948AB5A3C80BDDB5B0287E8B3.jambeck-testimony.pdf

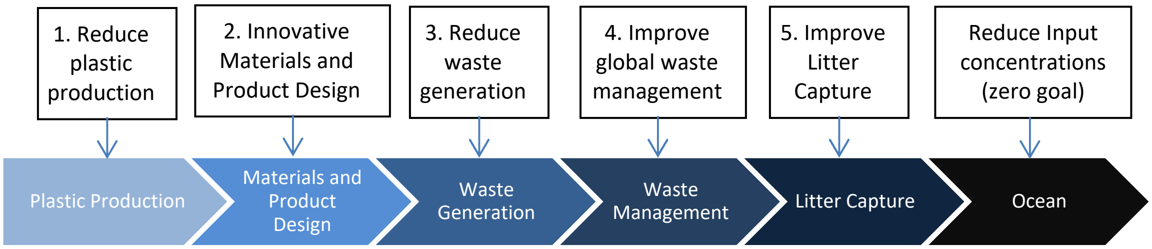

Figure 4. Intervention and Mitigation Strategies

1.0 Reducing plastic production

Plastic production is one of the "book ends" of the plastic value chain. Other than a few of the past 65 years, global plastic production has increased annually, and is anticipated to continue to do so into the near future. Although it comes from fossil fuels for the most part, and is produced from monomers that come from the processing of oil and natural gas, these monomers (e.g., ethylene and propylene) are used to make many different compounds, not just polymers. As long as other common chemicals are made, it is likely that polymers will continue to be made as well. And, as economies around the world continue to develop, packaged goods become more prevalent. Unless the industry changes its own course, this stage is mostly influenced if levers in other stages are pushed (e.g., demand is decreased for other reasons along the value chain). Reduction in demand can come from some points below:

1. Consumers demanding less packaging or no packaging (some markets)
    a. Not everyone has access to clean water, for example, so can't always make the choice of a reusable bottle, but these choices taken collectively where possible do make a difference
2. Local initiatives (e.g., bans, taxes)
    a. These are often very local-specific but are also becoming more common for items that are problematic to waste systems or our environment.
    b. Mass of items removed may be relatively small, but numbers of items are also important – there is more than one way to measure waste/products (e.g., mass, count, etc.)
3. Voluntary industry actions
    a. Industry has become more engaged on this issue – I wonder if they will volunteer some changes to help in the future as well?
    b. The reality is that all signs point to further growth in waste generation, as well as plastic use, especially where economic development is occurring or predicted to occur in the future

2.0 Innovative Materials and Product Design

New materials development and product design take time to advance, so these activities need to be happening now – and they are, but even more time and resource investment is needed. Overall, I think Green Engineering principles,[19] if followed during material development and product design, would help

[19] http://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/principles/12-principles-of-green-engineering.html

to avoid many of the externalities of plastic that we are dealing with currently. In addition, circular economy concepts, emerging all over the world now, will be important to also apply to plastic materials. Both of these guiding principles promote non-toxic materials, ultimately with the capability of biodegrading and/or being recycled. Materials and products made with more homogenous compounds would make recycling more efficient and effective. The University of Georgia has combined environmental engineering and polymer chemistry in a successful and rapidly expanding New Materials Institute with centers on biodegradable polymers and circular materials management to develop and test materials to reduce the flow of plastic into the ocean. NMI has become part of a National Science Foundation (NSF) Industry–University Cooperative Research Centers (IUCRC) that has over 30 corporate partners interested in more sustainable and biodegradable polymer products. These industry-research groups participate in pre-competitive research and development as new materials need to scale to be economical for all to use. There is no doubt that developing alternative materials without the unintended consequences of traditional plastics or other materials will spark innovation and economic growth in the USA where truly biodegradable polymer production facilities (e.g., Polyhydroxyalkanoates (PHA)), like the ones in Georgia owned by Danimer Scientific and RWDC, are creating jobs. There are many current corporate commitments to change materials, use more recycled materials, and be more circular with materials – many of these commitments have been made at the Our Ocean meeting that just occurred for the sixth time in Oslo Oct 23-24, 2019. $652 million was committed by governments, corporations and NGOs to reduce ocean pollution, including plastics. Commitments to move to redesign were made by Unilever and PepsiCo, for example, moving to reduction in virgin plastic use and increases in recycled content[20]. Specific points are given for redesign and material substitution below:

1. Sustainable packaging associations (pre-competitive collaborations)
    a. E.g., UGA's New Materials Institute IUCRC, Sustainable packaging coalition, Green-Blue: These pre-competitive environments could help develop alternatives, standardize packaging and help packaging retain value so that it is easier to recycle and less leakage will occur if it has value.
2. Packaging with more value (e.g., single, homogenous materials, design for recycling/end-of-life)
    a. This can be helped by collaborations between industry, brands and waste managers/experts
3. Design out problematic items/materials (e.g., caps/lids)
    a. Similar to how aluminum can "pop-top" opening was changed to a tab that stayed on (so the pull tabs did not get littered), we can innovate design for items that leak into the environment (if data is collected – see intervention point 5, last chance capture).
4. Truly biodegradable alternatives (e.g., PHA)
    a. PHA is expanding in the market in the USA and is creating economic value (new facility opening in Kentucky – several open in Georgia already). While it may biodegrade if littered in the environment, it should still be managed in the solid waste system, and be thoughtful about where used (in currently non-recyclable items, for example). But it has the possibility of being home-composted as well. The USA is currently a leader in the development of this material.

[20] https://ourocean2019.no/wp-content/uploads/2019/10/20191025-Commitments-1616.pdf

    b. An important distinction should be made with polylactic acid (PLA), a popular corn-based polymer is bio-based and industrial compostable (avoids using fossil fuels as feedstock), but it will not biodegrade in home composting or in the ocean. It will not biodegrade if littered on land. It has to reach a high temperature (reached in industrial composting) to be able to biodegrade.

3.0 **Reduce Waste Generation**

In places like the U.S., where we already have high per person waste generation rates, we can examine methods of waste reduction. For example, some of us have the luxury of being able to make choices about single use items we use daily. The majority of us have access to clean drinking water infrastructure so we can use a reusable water bottle, reusable coffee mug, bring a reusable bag to the grocery store, and say "no" to straws (or get reusable ones). These seem like small and mundane things, but what our research on plastic input showed is that since population density is such a big driver of these inputs, just one small choice, taken collectively, can make a big difference. There is a bit of a "chicken and egg" scenario here though, <u>consumers can make choices, but they also need availability and access to those choices</u>. For example, it might be hard to not buy bottled water if you don't have access to a drinking fountain or water filling station. *But this is also where policies regarding specific items of concern can provide motivation.*

Waste reduction can also occur from participation in new collaborative and sharing economies. These new paradigms are emerging and technology and social media are helping to move them forward. People are choosing to own less and "share" more. It started with car and bike shares, but has expanded to tools, and even clothing. As people become more aware of the issue of plastic in our environment, they are demanding companies reduce waste themselves, and help provide the right choices and infrastructure for people to reduce their own waste generation. Specific points on waste reduction below – and asking the question, *can we decouple waste generation from economic growth?* I get very excited to see what my students and young innovators will create in this category daily.

1. Using reusable items (e.g., bottles, mugs, bags, etc.) and if this is challenging for citizens, I ask them to think about why and what change is needed so it is possible at the government or corporate level? Then advocate for that change.
2. Sharing, Collaborative Economy concepts
    a. Bike shares, car shares, tool shares, clothing rental, etc. these all reduce the need to purchase and create waste (facilitated by technology), but still meet people's needs and can still create revenue for the companies providing the services.
    b. How can these concepts be related to packaging? (see 2.b)
3. Decouple waste generation with economic growth (facilitated by technology)
    a. Reuse programs (using mobile phones, which many people have globally, especially where rapid economic growth is occurring)
    b. RFID, mobile phones, smart-labels, etc. (e.g., RFID water refill stations exist for both Coca-Cola and PepsiCo products, but are not yet widely distributed yet)
    c. Reuse of cup systems, mobile dishwashing units, etc.

4.0 Waste Management Infrastructure

Globally, innovation and creativity is needed in this space and people are heeding the call. Some concepts that can be drivers in this area: zero waste (reduce disposal or destruction of waste to as close to zero as possible) and product stewardship/extended producer responsibility (waste management responsibility is shared or is the entire responsibility of product manufacturers). Plastic reuse and recycling can grow if the right economic structure is in place to motivate the collection of plastic waste and its reprocessing. Many local groups in global communities need some added support to elevate and expand what they are already doing to bring it to scale. Policies like deposit-return schemes reduce the quantity of plastic that reaches the environment. In US states that have these schemes, a 40% reduction of beverage containers is observed.[21]

Product stewardship is an important concept to discuss here. From an engineering standpoint, when a company wants to build a development/civil engineering project, there often is a partnership with the community. One example, I live near an above ground storage tank farm, and trucks come and go from it regularly. There were likely road improvements needed to be able to build the tank farm and the company who constructed it may have contributed to that infrastructure since they were building at this site. In some ways, this can be analogous to selling products without infrastructure to manage or recycle the waste created from those products. I think companies want to help based upon new awareness, but we are certainly playing “catchup” with the issue now. Besides policies, some companies are doing this individually, but many still don’t know how to help with infrastructure. And it requires cooperation with the public and private waste management systems in place already. I think that facilitating this in some way could be significant – maybe it will all be public-private partnerships, but some thought could go into how to facilitate companies engaging in shared responsibility. Ultimately it will take shared actions by industry, municipalities, and citizens to make significant positive change on this issue. As often said, there is no one solution to this issue, but an integrated approach is needed.

Solid waste collection can be a hyper-local activity and can look different in each country, city and even neighborhood. Plastic has made it a more complicated and created a rapid change in the waste stream that we were ill prepared for. It creates a waste stream that is more varied and dynamic than we have ever experienced before. It has proved to be quite a challenge for waste operators and municipalities to manage. I have developed a “Five C” approach for this intervention point.

1. **C**ollect: May be traditional, on-demand, or decentralized waste collection
    a. Collection innovation is needed – reverse logistics may play a role
2. **C**apture: Material Recovery Facilities, waste depots, waste banks, community centers
3. **C**ontain: Recycling or engineered disposal
4. **C**ontext and 5. **C**ulture – these can “make or break” the success of a potential intervention. The local community and stakeholders absolutely need to be engaged and involved from the start

[21] Schuyler, Q., Hardesty, B.D., Lawson, TJ., Opie, K., Wilcox, C., Economic incentives reduce plastic inputs to the ocean, Marine Policy, Volume 96, 2018, Pages 250-255.

through the end of any project and not just led through it, but local and indigenous knowledge is critical to community success.

5.0 Litter Capture

Because the focus of this hearing is on solid waste management and recycling, this section is mostly relevant for data collection to inform upstream decisions. Litter capture and collection is the last point to keep materials from entering the ocean. It is reserved for mostly the litter that occurs from inadvertent littering, lack of awareness and behavior issues. After outreach and education to prevent litter in the first place, there are street sweeping, municipal litter clean-up programs and stormwater catchment systems, all which will only be conducted in their respective jurisdictions. Non-governmental organization and volunteer cleanups to remove litter have been occurring for years. These events certainly help to keep litter from entering the ocean, and they are also a source of data. The Ocean Conservancy's International Coastal Cleanup is now in its 34th year and it not only helped to remove 0ver 10,500 metric tons of debris from beaches in 2018, but it has spread awareness and education as well. For the first time in 2017 and also in 2018, the top ten items found on beaches for the ICC were all plastic. In 2011, my colleague Dr. Kyle Johnsen and I co-developed a mobile app called Marine Debris Tracker at the University of Georgia funded by the NOAA Marine Debris Program. The Marine Debris Tracker mobile app and citizen science program allow for the collection of global standardized data at a scale, speed, and efficiency that wasn't previously possible [22] It also spreads awareness and education about this issue wherever it is used. Individuals all over the world have helped to clean-up or document over **2 million** items – by simply hitting a few buttons on their mobile phone to tell us what they found. User metrics provide a ranking and our largest group user is the Georgia Sea Turtle Center protecting and caring for Sea Turtles on Jekyll Island, GA and one of our largest individual user is in Omaha, NE (not far from the Missouri River) where he has collected over 87,000 pieces of litter alone, over the past 7.5 years. We, along with our app users, have fostered an online community through social networks – everyone is supportive of each other's efforts and individuals know that they are a part of a large global effort. There is now enough (opportunistic) data in the database to start to examine characteristics and trends based upon the spatial and temporal data provided by our extremely dedicated users. Data is critical to informing upstream solutions and can really empower communities and decision-makers to be able to take actions driven by data. Last-chance cleanup points are summarized below.

1. Engineered, mechanical systems
    a. Mr. Trash Wheel or other engineered devices – that also collect data on what is captured
2. Manual (by hand)
    a. Cleanups (e.g., ICC by Ocean Conservancy)
    b. Use of ocean-bound plastic can catalyze the development of infrastructure since the material now has value – often a much higher value than it did previously (e.g., Parley, Dell, NextWave plastics)

[22] Jambeck, J.R., Johnsen, K. (2015). Marine Debris Tracker: Citizen-based Litter and Marine Debris Data Collection and Mapping, *Computing in Science and Engineering,* 17(4), 20-26; http://www.marinedebris.engr.uga.edu/

3. Data to feed back to Interventions 1 through 4 in the Framework
    a. E.g., Marine Debris Tracker developed by UGA (or other apps) to collect data
    b. Could make upstream choices/changes based upon what is leaking into the environment

Trade-offs and Life Cycle Assessments

While Life Cycle Assessments (LCA) analyze data from cradle to grave in a holistic quantitative manner, and may include things like cost, energy, carbon equivalent emissions and other emissions data, there are some indirect impacts that a product may have at its end-of-life that are not covered by the typical "grave" (e.g., disposal/landfill/waste-to-energy) scenario. I have conducted Life-cycle assessments (LCAs) on various waste management scenarios myself[23] and here are some examples of trade-offs that we might consider while thinking about plastic. We are not going to get rid of all plastic, but I think we need to be more thoughtful about where, when, and how we use it.

Certainly plastic has brought light-weight benefits to food packaging, transport and allows food to be stored in sanitary ways, protecting the embodied energy that went into that food. Many times the carbon footprint of that food is large. Something to ponder, where do we draw the lines in these analyses? Why does our food have such a high carbon footprint/embodied energy? Should all food be distributed through the current model if it requires plastic packaging? I encourage people to think "out of the packaging container" and outline all the ways we can change the delivery of products and design of packaging. But, the best thing, environmentally-speaking, is to not produce any waste in the first place, so that lends itself to reusable items.

However, for when packaging is needed, what then, should it be made out of? More upstream, product LCAs can inform packaging choices, so we can compare carbon footprint, energy use, water consumption, etc. of two products, for example a plastic v. a reusable bag. While the energy input or carbon footprint for production, for example, may be more for the reusable bag, the fact that you do not have to manage waste after it's end-of-life is an energy and carbon off-set. While the plastic bag is light, it will have to be transported to a recycling or disposal facility and then managed there. In a carbon balance scenario, plastic does not release carbon at end of life, because as far as we know it does not practically degrade, so while it is not a benefit that it remains forever in a landfill, it does not release carbon while there. In addition, plastic bags have been known to jam up recycling systems at material recovery facilities (MRFs) and blow from landfills, making containment a challenge (and requiring human effort and machines to manage at landfills). These two situations do not fit into an LCA in a straight-forward way. And a last major limitation of this kind of LCA is that there is no way to include a littered plastic bag ending up in the ocean and a turtle eating it and dying. Animals killed from plastic litter does not fit into any LCA. So there are trade-offs that are a challenge to compare, and we need a better way

[23] Jambeck, J., Weitz, K., Townsend, T., Solo-Gabriele, H., (2007). CCA-treated Wood Disposed in Landfills and Life-cycle Trade-Offs With Waste-to-Energy and MSW Landfill Disposal in the U.S., Waste Management, Volume 27, Issue 8, 2007, Pages S21-S28. http://www.sciencedirect.com/science/article/pii/S0956053X07000773
Thorneloe, S., Weitz, K., Jambeck, J., (2007). Application of the U.S. Decision Support Tool for Materials and Waste Management, Waste Management, 27 (2007) 1006–1020. http://www.sciencedirect.com/science/article/pii/S0956053X0700058X

to look at the systems holistically, even beyond our typical LCA. At a minimum, we need to be able to acknowledge, and talk through some of these tradeoffs, in a systematic way.

And retail plastic bags are *often* noted as nuisances for waste management managers/operators. They can blow out of waste collection vehicles and blow around and away from landfills. The total cost of trash fences and keeping the area around the landfill clean (including labor cost of cleaning plastic bags from trees, fences, etc. as required by regulations) throughout the nation by waste management facilities has not been quantified, but there are recommended methods of practice.[24] Plastic bags incorrectly put into a recycling bin can get tangled the conveyor belt system and cause downtime (which can be expensive) at materials recovery facilities.

So, consumers almost exclusively have to make a conscious decision to save and then bring their retail plastic bags to a retail store for recycling. They must remember to take them inside the store and look for the recycle bin to deposit them in. These efforts are conscious and deliberate, and not likely to be made by people who are not cognizant of, or care about, our environment. And, for those people that are truly environmentally aware and conscientious, they will be likely to try and use reusable bags. So, without any other incentive, the percentage of people using plastic bags that are environmentally aware and willing to take the effort to recycle them in a non-curbside location is likely going to be lower than the percentage of people who are simply willing to recycle.

More Human Dimension in Solid Waste Management and Recycling

Work conducted in my research group on studying the human dimension of recycling by one of my graduate students, Dr. Eliana Mozo-Reyes, ended in the invention of a recycle bin and measuring a 50% increase in recycling with the WeRecycle bin that provided immediate eco-feedback to users (like a "Fitbit" for recycling)[25]. Our society's management of solid waste is complex and different than other urban infrastructure such as water, wastewater, and energy systems in that the act of "management" still requires public participation. Unlike water, sewer, and energy systems where management occurs because of technology and physical infrastructure (e.g., faucets, toilets, and power grid/lights), solid waste management still requires a person to make an effort to dispose of items in the home or in public areas. While conservation in other urban systems could require effort, technologies for water, wastewater, and energy conservation exist that do not require a change in human behavior (e.g., low flow faucets and toilets, and compact fluorescent lighting); however, conservation in solid waste (e.g., recycling) does necessitate a conscious choice and a change in human behavior, even at home. In public areas, the effort required can be even greater, as waste and recycling bins may not be directly accessible to the user; however, when performed, the management of waste in public areas can be a highly visible environmental activity observed by many people. In order to reach federal goals of recycling and community goals of "zero waste," recycling in and outside the home must be targeted for increase.

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[24] https://www.mswmanagement.com/landfills/article/21116988/landfill-managers-notebook-engineering-your-litter-control-efforts-part-1

[25] Mozo-Reyes, E., Jambeck, J.R., Reeves, P., Johnsen, K. (2016). Will They Recycle? Design and Implementation of Eco-feedback Technology to Promote On-the-go Recycling in a University Environment, *Resources Conservation and Recycling,* 10.1016/j.resconrec.2016.06.024.

Recycling can be evaluated from a social ecosystems point of view, including behavioral factors that have been underexplored such as interactions between individuals and communities and the inherently cooperative nature of pro-environmental actions[26]. The study of community-based behavioral change has resided largely within the social work profession because of the discipline's emphasis on the dynamic nature of person-environment interactions. Ecosystems theory, in providing the unifying conceptual framework for social work research and practice, underscores that at the individual level, human behavior is shaped by the complex interplay among micro, mezzo, and macro systems. At the macro system level—which includes culture, communities, institutions, and organizations—change is characterized by three principles: 1) the law of the few (e.g., "innovators, ambassadors, salesmen, connectors, and mavens"), 2) the stickiness factor (i.e., something to keep it interesting), and 3) the power of context[27]. Most successful behavioral interventions occurred in communities following these principles, as explored by Gladwell in his book The Tipping Point[28]. Previous research on recycling in community settings has demonstrated the benefits of involving the community in developing, analyzing, and participating in recycling strategies. Visibility, convenience, and information are complementary factors in encouraging people to recycle[29]. Disseminating information about the amount and type of material recycled addresses an information gap aspect about recycling that people find discouraging; by providing information, recyclers get to "peek behind the curtain," increasing their desire to participate in recycling[30]. In general, providing information or feedback to users appears to motivate the public to recycle, especially when a bin is visually salient[31].

Community-Based Data Collection and Assessment

Communities are the at the front lines of this issue. They are where solid waste is managed and many decisions and development of waste management systems are made. They also experience the direct impacts of plastic pollution in their local environment. It is important we work with communities in the decision-making process to be able to come together on realistic and viable solutions. After I began traveling for the US State Department for the International Informational Speakers Program in 2017 (that has now brought me to 13 countries), I often find myself in the same situation over and over again. Speaking with governments and communities about this issue, they would say to me, "Well now that we know more about this issue, what can we do?" and I would pause (since I had not often been there very long typically), and tell them that they have the local and indigenous knowledge for solutions to this

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[26] DiSalvo, C., P. Sengers, and H. Brynjarsdóttir. Mapping the landscape of sustainable HCI. Proc. CHI '10: 1975-1984.
[27] Burke, W. Organization Change: Theory and Practice. Third Edition. Sage Publications. 2011. ISBN: 9781 412978866
[28] Gladwell, M. The Tipping Point: How Little Things Can Make a Big Difference. Little Brown. 2000. ISBN 0-316-31696-2
[29] Kelly, T.C., Mason, I.G., Leiss, M.W., Ganesh, S. University community responses to on-campus resource recycling. Resources, Conservation and Recycling 47:1, 42-55. 2006
[30] Katzev, R., & Mishima, H. R. (1992). The Use of Posted Feedback to Promote Recycling. *Psychological Reports*, *71*(1), 259–264. https://doi.org/10.2466/pr0.1992.71.1.259
[31] Montazeri, S., Gonzalez, R., Yoon, C., & Papalambros, P. Y. (2012). Color, Cognition, and Recycling: How the Design of Everyday Objects Prompt Behavior Change.In Proceedings of the 12th International Design Conference DESIGN 2012 (pp. 1363-1368).

issue – they know their own context and culture. But I could also look around and take note of what I saw to contribute data for them to use… from what stores and cafes were selling in packing, from waste and recycle bins I saw, to litter on the ground. I also thought more about the concept of the circular economy – being touted as a solution to this issue, what does it really mean at the community level? How does a community move closer, or even see where they are at, related to the circular economy? In addition the community systems are an inherently complex, sociotechnical system, which is difficult to define with traditional metrics. There was a need for a methodology and a framework that provides a baseline understanding, illustrates the impacts of changes in the system, and facilitates useful knowledge exchange between cities, while allowing for flexible adaptation to local knowledge and expertise.

This is the context for how our Circularity Assessment Protocol (CAP) was developed in our Center for Circular Materials Management (the only center of its kind in the USA), in our New Materials Institute at the University of Georgia. Conducted in collaboration with a community and eventually by the community itself, the CAP characterizes seven community components: 1) inputs, 2) consumers, 3) product design, 4) use, 5) collection, 6) end-of-cycle management (e.g., waste management), and 7) plastic leakage into the environment. Various influencing factors drive this system including governance, economics, policy and legislation (e.g., bans, taxes, extended producer responsibility). Furthermore, multiple stakeholders exist at every level of the CAP influencing the complex system and these include citizens, government, industry, NGOs and academia. While the hub and spoke model illustrates the CAP (Figure 5), it is a complex system with components inherently interconnected to each other and to life-cycle impacts beyond each component.

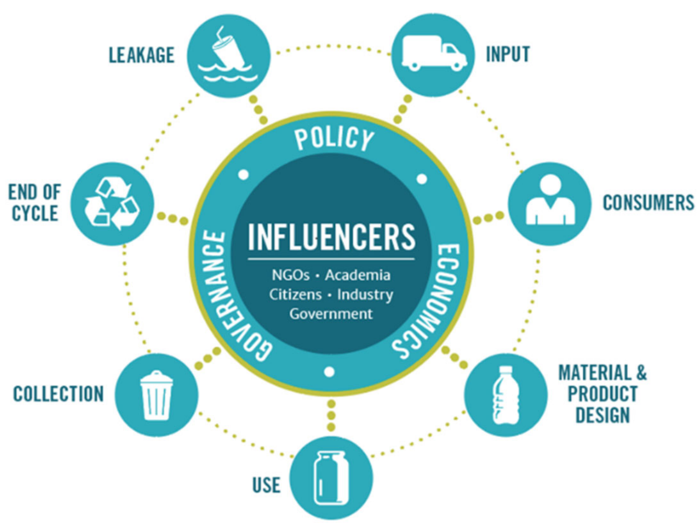

Figure 5. The Hub and Spoke model of the Circularity Assessment Protocol (CAP)

The framework supports points of intervention and actions, including guidance on effective impact (in terms of environmental and economic) to improve circularity. The CAP can help to inform a community by giving them a sap-shot baseline assessment to work from and direct potential actions to take to improve the areas that most need it, and to answer specific questions they have about their own community. The CAP can inform and support the government to define policies and good practices related to solid waste management and infrastructure, including facilitating an understanding of solid waste and plastic management through a social lens. This can provide an understanding of people's actions which will inform policy and interventions. The CAP is being used for projects funded by the World Bank, National Geographic, the Asia-Pacific Economic Cooperation (APEC) through the Ocean Conservancy, and USAID all around the world, but also in at least two places in the USA, one small community and a large metropolitan coastal city. Similar to RCRA in the 1970's, sound science should be used when determining policies and solutions and community-based data collection can not only contribute to this science but engage and empower a community to make change.

The U.S. can be a Global Leader in Solid Waste Management

As environmental engineers and solid waste experts, we manage all solid waste that comes our way. But by realizing that we should be thinking about end-of-life in materials development and product design stages, we can shift the paradigm of "waste" to materials management. Also, the worldwide interest on this topic has put the spotlight on solid waste management infrastructure needs, and so we need to collectively come up with creative, socially and culturally-appropriate strategies. By changing the way we think about waste, reducing at source, designing products for their end-of-life management, valuing secondary materials, collecting, capturing and containing our waste, we can open up new jobs and opportunities for economic innovation, while conserving our planet and resources for future generations.