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A TOOL FOR EVALUATING ENVIRONMENTAL SUSTAINABILITY OF PLASTIC WASTE REDUCTION INNOVATIONS

Gregory Keoleian, Team Lead
Martin C. Heller
Michael H Mazor
Shelie Miller

Student contributors:
Adrienne Watts
Connie Chow
Dengfeng Qin
Ruimin Yang
Jake Calzavara

CENTER FOR SUSTAINABLE SYSTEMS
UNIVERSITY OF MICHIGAN

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Gregory Keoleian, Team Lead
Martin C. Heller
Michael H. Mazor
Shelie Miller
Center for Sustainable Systems

University of Michigan
Ann Arbor

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Gregory Keoleian, Martin C. Heller, Michael H. Mazor, and Shelie Miller
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Center for Sustainable Systems
School for Environment and Sustainability
University of Michigan
440 Church Street, Dana Building
Ann Arbor, MI 48109-1041
Phone: 734-764-1412
Email: css.info@umich.edu
Web: http://css.umich.edu

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Acknowledgments

The research for developing this report and the Plastics Waste Reduction Innovation Sustainability Evaluation Tool (PRISET) was funded in part through the Morgan Stanley Plastic Waste Reduction Research and Fellowship program established between the Center for Sustainable Systems and Morgan Stanley. We wish to thank our collaborators at Morgan Stanley including Jacqueline Lewandowski and Courtney Thompson, and Ellie Moss at Encourage Capital for their regular meetings with our team and their guidance throughout this research.

This report builds upon two projects also funded through the Morgan Stanley Plastic Waste Reduction Research and Fellowship program. The first project generated the first contemporary plastics material flow by resin type through the US economy, encompassing production, sales, use markets and end-of-life management. The output of this research was a journal publication: "Plastics in the US: Toward a Material Flow Characterization of Production, Markets and End of Life" *Environmental Research Letters* (2020) 15(9): 1-14. 094034. The second project was a University of Michigan School for Environment and Sustainability Masters project, where Connie Chow, Dengfeng Qin, and Ruimin Yang developed an earlier version of the PRISET tool. These three graduate students were advised by Greg Keoleian, Michael Mazor, and Marty Heller along with our collaborators Jacqueline Lewandowski and Courtney Thompson, and Ellie Moss.

Executive Summary

Plastic materials have become pervasive in 21st century economies, yet **60% of all plastics ever produced globally have been discarded either in landfills or elsewhere in the environment**. A recent characterization of plastics manufacturing, end-use, and waste management in the US is shown in Figure ES1 and the majority of these plastics are disposed in landfills. This represents not only significant economic and material resource losses, but accumulation of plastics in natural environments can also impact wildlife and ecosystem wellbeing. Efforts to address plastic waste concerns are vast and diverse, involving every stage of the plastic supply chain, including development of alternative materials; innovative design and re-design of products and packaging systems; and improvements in recycling processes and markets. Such advancements will require capital investment, and as such, strategic investors can influence the rate and direction of plastic waste reduction efforts. Experience from industrial ecology and related fields demonstrates that reducing plastic use or plastic waste does not necessarily result in reduction in environmental sustainability indicators such as energy use, greenhouse gas emissions, and water use. Additional guidance is needed to assure that promising plastic waste reduction innovations also meet broader sustainable development goals.

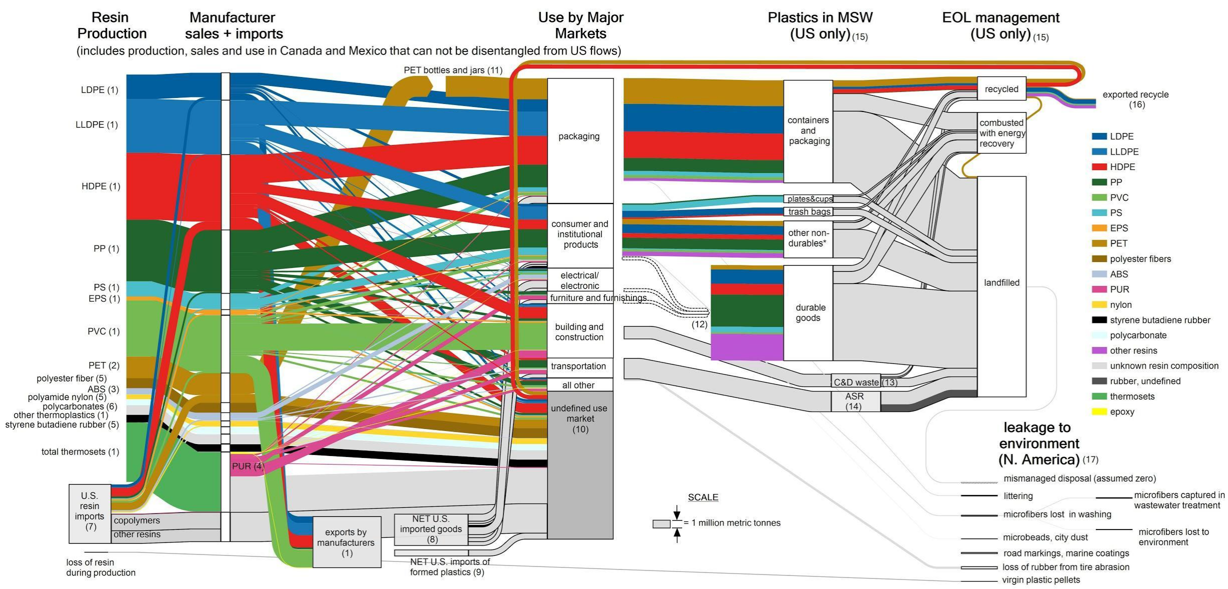

Figure ES1. Production, imports, exports, use, disposal and leakage of plastics in the US in 2017.

This report introduces the **Plastic waste Reduction Innovation Sustainability Evaluation Tool (PRISET)**. The aim is to provide a guide for experts and non-experts to assess the sustainability performance of emerging products, technologies and services that can reduce plastic waste. The basic structure of the tool is shown in the figure ES2.

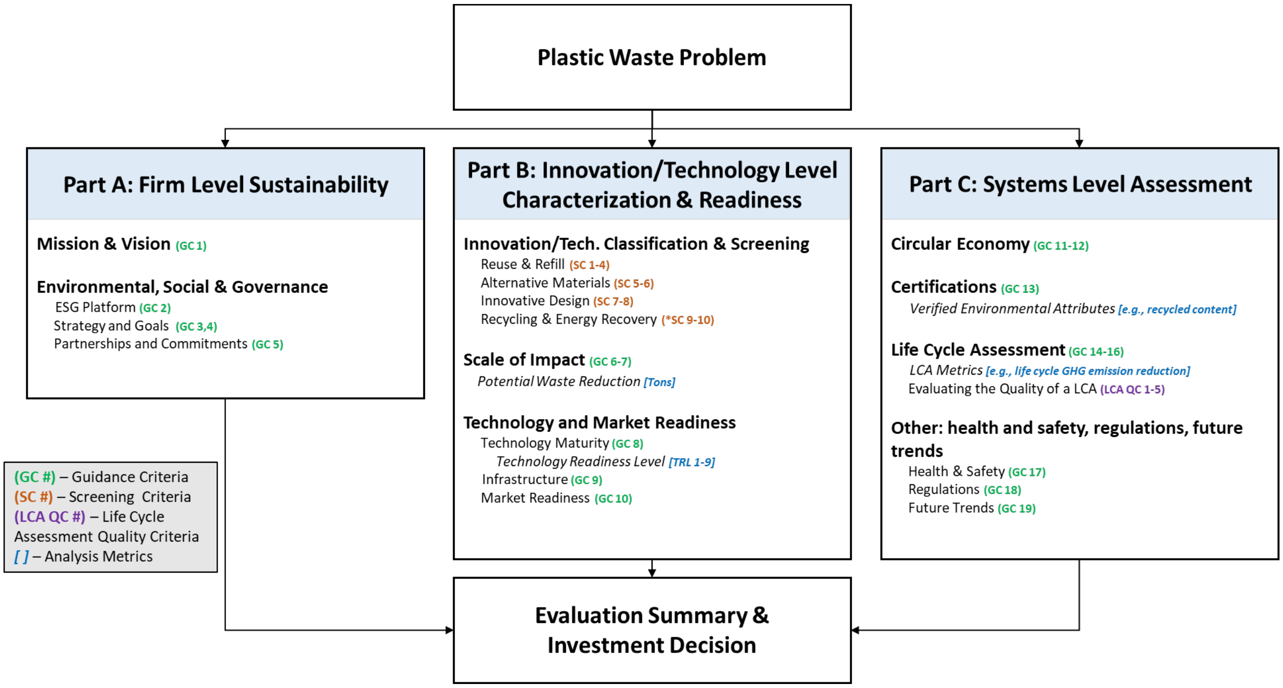

Figure ES2. The PRISET Structure, Analysis Criteria, and Metrics.

PRISET builds upon existing frameworks, tools, knowledge bases and experiences of industrial ecology, life cycle assessment, circular economy and ESG reporting. This tool distills insights from these often complex and time-consuming assessment frameworks into 19 main *Guidance Criteria* structured within three Parts:

Part A Firm Level Sustainability Strategy, Goals and Governance;
Part B Innovation/Technology Characterization and Market Readiness; and
Part C Systems Level Sustainability Assessment.

In addition to the main guidance criteria, the Tool includes *Technology/Innovation Specific Screening Criteria* and *LCA Quality Criteria*. PRISET serves to support analysts and other staff at investment firms and their clients with the evaluation of environmental sustainability in their investment decision making. Here is a brief description of the three Parts.

Part A Firm Level Sustainability Strategy, Goals, and Governance

This set of guidance criteria helps identify the extent to which sustainability is a priority for the organization and the extent to which sustainability principles are embedded within the organization's culture and practices. These criteria help evaluate whether or not there is a serious, demonstrated commitment by the organization, as indicated by their **Mission and Vision** and **ESG** including sustainability strategy and goals, and active partnerships and public sustainability commitments.

Part B Innovation/Technology Level Characterization and Market Readiness

In the **Technology/Innovation Classification and Initial Screening** the waste reduction innovation is first classified into one of four general categories:

- **Reuse/Refill**
- **Alternative Materials**
- **Innovative Design**
- **Recycling and Energy Recovery**

Technology/Innovation Specific Screening Criteria are then used to help analysts develop an initial examination of an innovation's environmental merits. Understanding the **Scale of the Potential Waste Reduction Impact** helps determine whether or not the innovation will have a significant impact on the plastic waste problem both in terms of the magnitude of the waste reduction and the level of difficulty in solving the problem.

Examining the **Technology and Market Readiness** with guidance criteria and the *Technology Readiness Level (TRL)* metric helps assess the overall viability of the innovation, both in terms of whether its technical attributes are of sufficient quality to make it competitive within existing markets and whether there are potential logistical or behavioral barriers that need to be addressed. For example, even if a material *can* be recycled, there must be recycling infrastructure in place in order achieve any benefit. Similarly, consumers must actually participate in plastic return programs for extended producer responsibility initiatives to work. Therefore, it is important to evaluate how potential business plans will overcome logistical and/or behavioral barriers in order to realize the benefits of an innovation as designed.

Part C Systems-Level Sustainability Assessment

This set of guidance criteria helps evaluate the sustainability of an innovation, with an emphasis on environmental performance. Firms may use **Certifications** as a verification of specific environmental attributes of an innovation such as the percentage of recycled content in a product material. Using tools such as **Circular Economy Principles** and **Life Cycle Assessment**, the benefits as well as potential tradeoffs that may be associated with the innovation can be examined in more detail. Life cycle assessments are a comprehensive evaluation of an innovations environmental footprint including metrics such as life cycle greenhouse gas emissions, energy consumption, solid waste generation, and water use impacts. LCA can be used to compare the impacts of an innovation with incumbent system responsible for the plastic waste being targeted. Comparative LCA require an external peer review in order to make any marketing declarations about an innovation. Estimating the environmental impacts of new innovations is rarely a straightforward process. Additional guidance is provided to assist analyst in evaluating the quality of a life cycle assessment if one has been conducted.

Box ES1. PRISET Guidance Criteria

Part A Firm Level Sustainability Strategy, Goals, and Governance

Mission and Vision

GC 1 Does the mission and vision convey a purpose that contributes to advancing sustainability?

Environmental, Social, and Governance (ESG)

Standardized reporting
GC 2 Does the company report to major standardized ESG platforms such as Global Reporting Institute (GRI), Sustainability Accounting Standards Board (SASB), or the Task Force on Climate-Related Financial Disclosures (TCFD)?

Strategy and Goals
GC 3 Does the company discuss and detail their climate strategy? Are specific, measurable goals articulated in this plan?

GC 4 Does the company outline a specific sourcing strategy that aligns with their environmental strategy?

Partnerships
GC 5 Does the company have and maintain key partnerships? Is the company involved in commitments and initiatives that demonstrate commitment to environmental strategy?

Part B Innovation/Technology Level Characterization and Market Readiness
Technology/Innovation Classification and Initial Screening (technology specific screening criteria – See Section 4.1.)

Scale of waste reduction
GC 6 Does the intervention target a product with a high likelihood of losses to natural environments, a difficult to recycle plastic or product, or other high priority waste stream?

GC 7 What is the maximum potential for this intervention to reduce plastic use/waste?

Technology and market readiness
GC 8 Is the technical quality of the innovation sufficiently competitive?

GC 9 Does the required physical and/or logistical infrastructure exist to support adoption of the innovation? What infrastructure changes may be required?

GC 10 Are there social or behavioral changes required for the innovation to be effective? What efforts will be made to support this change?

Part C Systems-Level Sustainability Assessment

Circular Economy Principles (2 criteria)
GC 11 Does the innovation build upon Circular Economy Principles?

GC 12 How are materials used for the innovation managed at end-of-life?

Certifications
GC 13 Has the company acquired appropriate certifications to distinguish their service or products?

Life Cycle Assessment with supplemental criteria for evaluating the quality of the LCA
GC 14 Has a reputable and robust life cycle assessment (LCA) been conducted in accordance with ISO standards that indicates potential for significant environmental improvement?

GC 15 Does a comparative LCA demonstrate performance advantages over the status quo?

GC 16 Has the academic literature pertaining to products/services that are similar or related to the innovation been reviewed? What has this review revealed as critical parameters for determining environmental performance or issues of concern?

Other Health and Safety, Regulations, Future Trends
GC 17 Has the health, safety, and rights of all potentially impacted individuals been considered and respected?

GC 18 Are there anticipated potential regulatory risks or avoided risks of the business model or product in question?

GC 19 Are there future trends (e.g. shifts in renewable energy consumption, changing regulatory environment) that would significantly impact the environmental profile or overall sustainability of the innovation?

The overall objective of PRISET is to assist practitioners to systematically assess innovations intended to improve the environmental impacts associated with plastic production, use, and disposal. The guidance criteria are intended to assess potential environmental improvements that may result from investment in a new innovation, as well as to identify areas of concern and determine where additional research may be needed. Therefore**, a negative evaluation on one or more of the guidance criterion should not necessarily be seen as disqualifying**. Instead, the tool is intended to assist in a holistic evaluation to better understand the benefits as well as potential areas of caution that may need to be addressed or further explored.

PRISET recognizes differences in the technology readiness level of plastic waste innovations. Different levels of technical maturity should be taken into account when applying the guidance criteria. One of the challenges for **early-stage** companies or innovations is that the technology may be less defined, and lack of data and uncertainty regarding deployment in market conditions will limit appropriate assessment methods. For **mature companies** whose technology is commercialized, **certifications, life cycle assessments**, or other quantitative analyses can offer more detailed assessment of environmental impacts as well as performance relative to incumbent or competing technologies/products/services. Detailed life cycle assessments and full certification may not be realistic for early-stage innovations, whereas there may be a higher standard that is applied to more developed technology. Further considerations that are specific to these technology categories are addressed using guidance criteria and metrics specific to the technology deployed, the market affected, and often the behaviors impacted.

PRISET is not an expert system that scores environmental sustainability performance of innovations. Judgement is ultimately required to incorporate guidance on environmental performance with other critical metrics used to evaluate potential investments. PRISET offers foundational background information and supportive direction for entrepreneurs, investors, consultants and other vested parties through what otherwise might be foreign and intimidating assessments. In addition, to serving an evaluation function **the tool can provide innovation companies a platform to improve their sustainability performance**.

This report concludes with the application of tool in a **Case Study** evaluation of ClubZero, a traceable, reusable cup service.

1. Introduction

Plastics – synthetic organic polymers – are pervasive in modern life. These versatile materials are low cost, lightweight, strong, durable, corrosion-resistant, and have valuable thermal and electrical insulation properties. When blended, co-extruded, or combined with performance enhancing additives (Hahladakis et al. 2018), the diversity of existing plastics exhibit a wide range of properties. This has made possible many technological advances and a tremendous array of plastic products, creating numerous societal benefits such as energy savings, light-weighting, and safety. The global use of plastics now exceeds most other man-made materials in nearly all industrial sectors, aside from construction where concrete and metals still dominate. Nonrenewable organics – predominantly plastics – were 4% of the non-fuel raw material put into use in the US in 2014; this increases to 15% when stone, gravel and sand are disregarded (Matos 2017).

Yet this extensive and often highly specialized plastics economy has also resulted in significant challenges in the end-of-life management of plastic products to recover and retain the economic and technical value of the materials. As a result, significant "leakage" of plastics out of the economy have occurred in the form of waste and plastics pollution. An estimated 4900 million metric tonnes (Mt) of the 8300 Mt total of plastics ever produced globally have been discarded either in landfills or elsewhere in the environment (Geyer et al. 2017). Plastics do not typically biodegrade, and their accumulation in and contamination of natural environments is an ever-increasing concern (Law 2017; Chae and An 2018; Notten 2018; Schwarz et al. 2019). As the vast majority of plastics are derived from fossil fuels, global production (including both feedstock and manufacturing energy requirements) currently represents around 8% of global annual oil and gas consumption (Hopewell et al. 2009). 3.8% of global greenhouse gas emissions in 2015 were associated with the 407 Mt of conventional plastics produced globally in that year (Zheng and Suh 2019) . In the United States (US), plastics production accounts for 1% of national greenhouse gas emissions (Posen et al. 2017). Projections based on current growth rates suggest that emissions from plastics could reach 15% of the global carbon budget by 2050 (World Economic Forum et al. 2016).

Emerging out of the concern with the state of plastic waste globally is an opportunity to reinvent the ways in which plastics are produced, used and disposed in order to move aggressively toward a system based in the principles of circular economy. A systemic shift to a circular economy involves designing out waste and pollution by reducing, reusing, recycling and recovering materials in production and consumption processes, within sustainable development aims (Kirchherr et al. 2017). There is broad interest in increasing the circularity of plastics in general, as evidenced by the rapid and widespread adoption of the New Plastics Economy Global Commitment (New Plastics Economy Global Commitment 2019). Supporting the innovation necessary for such a major shift in the role of plastics will require significant and directed capital investment. To cite one example, Morgan Stanley has committed to facilitate the prevention, removal and reduction of 50 million metric tons of plastic waste from entering oceans, landscapes and landfills by 2030 through its own activities and a variety of financial market investments and transactions. Recovering valuable plastic by shifting plastics' linear use to a circular economy can unlock a $706 billion economic opportunity (World Economic Forum et al. 2016).

Insights from industrial ecology and other fields within sustainability demonstrate that reducing plastic use and/or plastic waste does not necessarily result in reductions in environmental impacts such as energy use, greenhouse gas emissions, water use and water quality. Evaluation of these sustainability indicators requires a more careful consideration of the product or service system in question – ideally across its full life cycle, including energy and material resource procurement, manufacturing, use and disposal. Often this includes an understanding of both the currently existing (to be displaced) product or service *and* the displacing innovation. Such evaluations can be quantitatively performed within a life cycle assessment framework (see Box 7 in this report). LCA can be data and time intensive, however, and often there simply is not enough operational data with a new and potentially disruptive product, innovation or technology to properly conduct an LCA. The goal of the work described in this report is to draw on a broader collection of tools, knowledge and experiences to offer guidance to the investment and finance sector in evaluating the environmental sustainability of plastic waste reduction efforts. In short, we hope to help in identifying investments that have a strong potential to advance sustainability goals, in addition to offering sound financial returns and reducing plastic waste.

Objectives & Outcomes

The objectives of this project include helping investors and their clients:

1) Understand essential indicators of sustainability performance;
2) Characterize and classify plastic waste reduction innovations;
3) Develop a framework and tool to assess the sustainability performance of plastic waste reduction innovations.

2. Investment Guidance Tool: "Plastic waste Reduction Innovation Sustainability Evaluation Tool"

2.1. Development

There are numerous approaches to evaluating sustainability. Sustainability in its fullest sense considers social, economic and environmental dimensions. We cede expertise in economic sustainability to investment firms and business evaluators: thus, critical economic considerations are explicitly excluded here. Similarly, while social and environmental justice concerns are included, these often need more specific context and additional expertise. We focus the PRISET tool on environmental sustainability considerations and expose aspects, indicators and performance parameters that are particularly relevant to innovations aimed at reducing plastic waste. This involves implementing or borrowing from a variety of frameworks and methods commonly used when evaluating sustainability performance.

Background materials in support of the PRISET tool were researched, refined and then aggregated into the tool's guidance criteria by a UM SEAS Masters' Project student group during 2020-2021 (Chow et al. 2021), with guidance and input from CSS faculty and staff.

Sections 2.2 and 2.3 describe the structure of the tool and how it can be best used effectively. The remaining sections offer background and context for the guidance criteria through each step of the tool.

2.2. Structure

PRISET offers criteria to guide communication with and evaluation of the business under consideration for investment. Herein, we call this business the **focal firm**, and we will call the "waste reduction solution (product, process or service)" that the focal firm intends to implement the **innovation**.

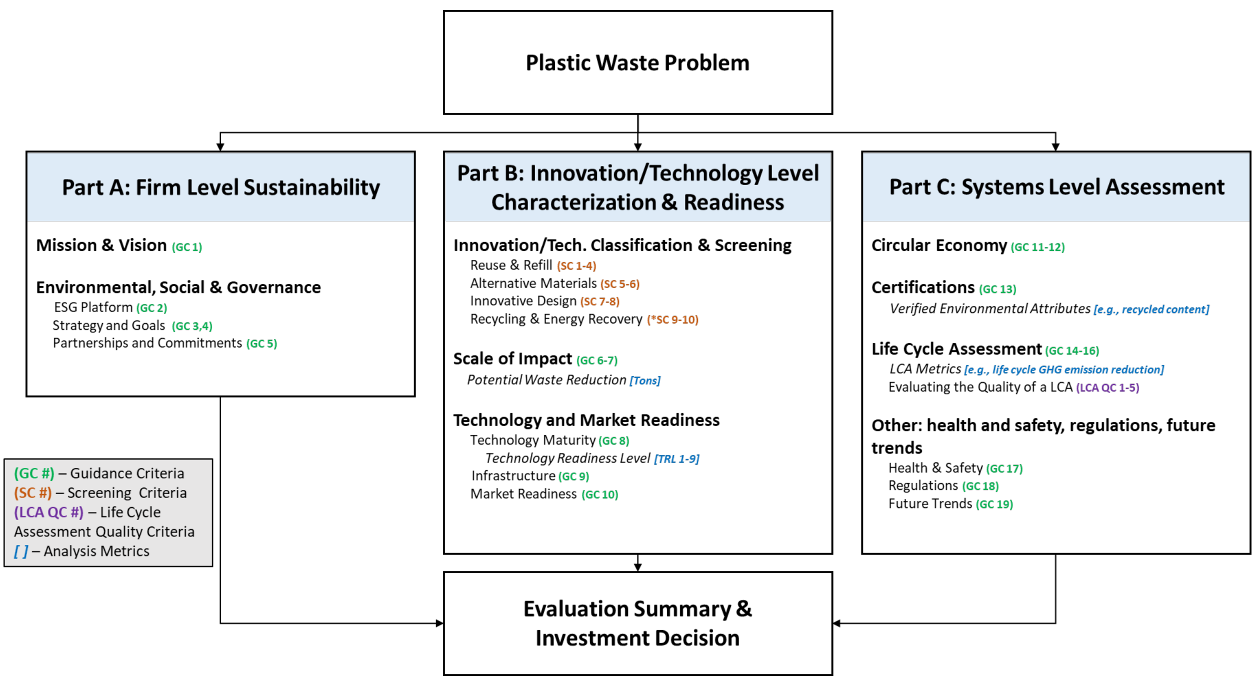

Figure 1. The PRISET Structure, Analysis Criteria, and Metrics.

PRISET is organized as seen in the diagram in Figure 1. Aspects of the focal firm's business philosophy - their mission and vision and environmental governance - are considered first. Innovations are classified and organized into one of four categories to facilitate a initial evaluation of environmental merit. We recommend evaluation of the potential for the innovation to scale and represent notable reductions in plastic waste and environmental impacts throughout the supply chain. There may be some innovations that are small changes per product, but could have a large aggregate impact in plastic packaging waste, for example. Or there may be innovations that appear transformative but only involve a very small market sector. For innovations that are at a higher stage of market maturity, it is reasonable to expect more specific information on environmental performance from acquired certifications and/or life cycle assessment to help inform an overall assessment. For innovations that are at a low technology readiness level, there may not be sufficient available data to conduct an LCA of the innovation. In the absence of LCA data or as a supplement, further considerations that are specific to the technology category employed in the innovation are then addressed.

2.3. Use

The tool provides guidance for investors to focus evaluation of the environmental sustainability of emerging innovations on critical criteria. It also plays an educational function to help investment firms and their clients to understand essential sustainability questions for focal firms engaged in innovations aimed at reducing plastic waste. Additionally, the guidance criteria can be used internally by firms as part of their environmental management and improvement process.

Many aspects of environmental performance are not regulated: for example, greenhouse gas emissions or non-hazardous landfill use. Thus, we recommend that PRISET be used as the basis of a conversation between investors and focal firms on current understanding of environmental performance as well as future plans for improvement or performance assurance.

It is important to recognize that the tool does not evaluate a focal firm's ability to reduce plastic waste, nor does the output from using the tool offer a comprehensive assessment of environmental performance. Consider it a tool for gathering and organizing relevant information. Judgement is required to incorporate guidance on environmental performance with other critical metrics used to evaluate potential investments. The January 2018 report from Morgan Stanley Research Embedding Sustainability into Valuation: The Next Chapter recognizes in their Environmental, Social and Governance (ESG) Integration Framework as element 5: "An active judgement call is required. There is no set of rules that can be applied to qualify as ESG integration." The information gathered through this tool can be considered as "observed facts that can reveal relative positions"(Searcy 2016).

3. Part A. Firm Level Sustainability Strategy, Goals and Governance

This set of guidance criteria helps identify the extent to which sustainability is a priority for the organization and the extent to which sustainability principles are embedded within the organization's culture and practices. These criteria help evaluate whether or not there is a serious, demonstrated commitment by the organization, as indicated by their mission, sustainability strategy, and active partnerships and public sustainability commitments.

3.1. Mission and Vision

Basis

Understanding the mission and vision of a company offers insight into their purpose, goals, and values. A January 2018 report from Morgan Stanley Research (Morgan Stanley Research 2018) describes internal and external research connecting corporate sustainability efforts and positive financial performance. Governance is identified as a key factor in evaluating environmental and other sustainability achievements.

Mission and vision statements should describe what the company is doing and what it intends to achieve.

Guidance Criteria 1

- **Does the mission and vision convey a purpose that contributes to advancing sustainability?**

Alignment with the purpose and intent of the focal firm offers a useful starting point for consideration of sustainability. While certainly not an absolute metric, mission/vision statements can communicate an expressed commitment to common values (e.g., plastic waste reduction). In addition to providing excellent products or services and reducing plastic waste, focal firms should be accountable to the benefit of employees, customers, society(Zu 2019), and the environment. Mission statements should consider the triple bottom line: people, planet and profits. Implementation of the intent laid out in a mission statement will, of course, determine performance, but intention is the first step. Look for phrases such as

- life cycle thinking
- life cycle design
- industrial ecology
- circular economy
- green engineering
- design for the environment
- holistic decision-making
- triple bottom line
- stakeholder view of the firm
- long-term value creation
- socially responsible
- protect the environment and benefit communities
- restore the environment
- embedded sustainability
- diversity and inclusion.

Sources of Information

Company mission and vision statements should be readily available, or at least available on request.

3.2. Environmental, Social and Governance

Basis

Considering the Environmental, Social, and Governance (ESG) structure as it relates to business philosophy is a key criterion to determine the focus of a company on sustainability through the organization of the focal firm. Other mechanisms of measurement discussed later in this report, such as Life Cycle Assessment (LCA), are focused on assessing the impacts of the innovation itself, rather than the structure of a company. In general, ESG criteria are a set of standards and metrics used by investment companies to screen for potential investment opportunities that are actively pursuing a business strategy rooted in positive environmental or social change or for companies that are actively trying to mitigate their negative impacts (Gordon, 2020). These standards are tailored to the specific goals set by an investor(Global Impact Investing Network). ESG indicators serve to characterize how the company is structured and makes decisions.

Guidance Criteria 2

- **Does the company report to major standardized ESG platforms such as Global Reporting Institute (GRI), Sustainability Accounting Standards Board (SASB), or the Task Force on Climate-Related Financial Disclosures (TCFD)?**

The three most common standardized ESG reports are the Global Reporting Institute (GRI) (GRI 2020), the Sustainability Accounting Standards Board (SASB) (SASB 2017), and the Task Force on Climate-Related Financial Disclosures (TCFD). These bodies have standardized reporting metrics for a wide variety of ESG indicators, such as non-renewable resource use, stakeholder engagement practices, and customer health and safety. Both the GRI and SASB report specific metrics on plastic use. These include indicators such as total plastic material use, total reclaimed products and packaging materials, and product design and lifecycle management (WWF and Accenture 2021). Standardized ESG reporting is best used to compare specific reported metrics across companies or potential investments. It is important to note there are often cost and other barriers to reporting to major ESG platforms particularly for start-ups and small companies. It is not uncommon that early-stage companies do not have the resources to build a full report, but they should consider what metrics and ESG indicators are relevant. Below are four ESG guidance criteria closely related to the environmental performance of the focal firm as it relates to plastic waste mitigation strategies and innovations that should be considered.

Another common standard is CDP (formerly Carbon Disclosure Project) (CDP Disclosure Insight Action).

Guidance Criteria 3

- **Does the company discuss and detail their climate strategy? Are specific, measurable goals articulated in this plan?**

Even if a product innovation reduces overall plastic waste, it may still cause worse overall environmental impacts such as increased greenhouse gas emissions (GHGs) (discussed in detail below). For example, if a reusable packaging model requires additional shipping or needs to be washed for reuse, total amount of plastic waste may decrease but overall GHGs could increase. Therefore it is critical that the focal firm detail its strategy to reduce their emissions, not only within the operations of the company, but also over the lifecycle of their product or service. A robust climate strategy should include an initial inventory of emissions in some defined baseline year, targets for emission reductions by a certain year, and a detailed plan of how they will achieve those targets. The details may include potential power purchase agreements arrangements, if they plan to use carbon offsets, and energy efficiency programs. The most complete climate strategies include the steps a company will take to reduce scope 1, 2, and 3 emissions; scope 3 emissions are the most difficult to measure and often represent the vast majority of a company's emissions (U.S. Environmental Protection Agency).

Guidance Criteria 4

- **Does the company outline a specific sourcing strategy that aligns with their environmental strategy?**

A detailed and robust sourcing strategy outlines what the business considers in the decision-making process of where and who to source raw materials from. Some tools that might be used in this assessment include definitions of responsible sourcing, supplier codes of conduct, and methods of sustainable procurement. Metrics and measurement of this strategy might include supplier scorecards (either standardized at an industry level or created by the company) and audit models (i.e. once a year) (Kuhn 2016).

Guidance Criteria 5

- **Does the company have and maintain key partnerships? Is the company involved in commitments and initiatives that demonstrate commitment to environmental strategy?**

Key partnerships, member organizations, and collaborations provide additional context to a focal firm's involvement in plastic waste mitigation landscape at-large. Below are a few examples of well-known commitments and initiatives in the plastic waste reduction space.

Table 1. Example of key plastic waste reduction initiatives and partnerships.

Name of commitment/initiative and sponsoring body	**Commitment Goals or Objectives**
The New Plastics Economy Global Commitment (Ellen MacArthur Foundation)	Eliminate problematic or unnecessary plastic packaging, move from single-use towards reuse models, and aim for 100% of plastic packaging to be reusable, recyclable or compostable by 2025 (New Plastics Economy Global Commitment 2019).
ReSource Plastic (WWF)	ReSource convenes organizations (corporations, governments, non- profits, etc.) focused on addressing the plastic waste crisis by 1) identifying highest impact areas ripe for reduction 2) assists in implementation of plastic reduction activities and measuring methodologies and 3) creates collaborative opportunities to generate new solutions and investments in plastic reduction innovations (ReSource Plastic).
The U.S. Plastics Pact (led by The Recycling Partnership, with support from WWF) and various other pacts by country.	The U.S. Plastics Pact convenes value chain actors (businesses, government entities, research institutions, non-profits, etc) to align stakeholders

	on a common vision of the circular economy for plastics (U.S. Plastics Pact).

Other collaborations and organizations include the Global Plastic Platform by the UN Environment Assembly, the Alliance to End Plastic Waste, the Commonwealth Clean Ocean Alliance, The Circulate Initiative, and #breakfreefromplastic (James 2019).

Sources of Information

Information on climate strategy and ESG reporting are typically found in a company's sustainability report. Key partnerships and collaborations can typically be found on a company's website, in their sustainability report, or on the website of the collaboration under members or partners. To find information on regulatory implications, wider research on policy for a country or state must be performed.

4. Part B. Innovation/Technology Level Characterization and Readiness

4.1. Technology/Innovation Classification and Initial Screening

The criteria that follow recognize that some of the important questions to ask about an innovation depend on what type of innovation it is. Here, we divide innovations into the broad categories of: reuse & refill solutions - programs aimed at replacing single-use products with some form of re-use; alternative materials - any innovation that replaces traditional plastics with other materials; innovative design - a loose category for “out-of-the-box” redesign that reconsider how function and service is provided; and recycling - those innovations that improve on end-of-life treatment and recapture. More than one category may be applicable for a given innovation.

4.1.1. Reuse & refill

Basis

Single-use plastic packaging, containers and other products are dominant contributors to plastic waste. Innovations aimed at reducing this waste through re-use or refilling schemes are prevalent. These can include business to business (B2B) reusable packages and containers as well as those marketed directly to consumers. Typically, reuse programs involve “recirculating” packaging / containers through multiple uses.

The evaluation of reusable containers requires consideration of the following:

- Some form of collection, return transportation, and cleaning is required and is additional to the incumbent solution.
- Reuse may introduce new plastic or other non-plastic material into a market.
- While size and shape may be maintained, package mass may increase and may impact processing, logistics, and use.

A comparative life cycle assessment is encouraged to establish the break-even point where further reuse will reduce total environmental impact (i.e., waste, energy, GHG) relative to incumbent. End-of-life of the reusable package must likewise be considered.

(Coelho et al. 2020) offer a valuable summary of sustainability considerations of reusable packaging. Their review of environmental impact studies of reusable packaging systems is reproduced in Table 2 below, and offers a good starting point for considering various reusable packaging formats.

Table 2. Summary of environmental impact studies of reusable packaging systems (adapted from (Coelho et al. 2020). References are listed in original).

Market	Packaging system	Key Findings	Reference
B2B	Drum (55 gallons)	Energy use over the life cycle of multiple-use drums is 65% lower, 75% reduction of solid waste.	Franklin Associates (1999)
	Steel drums, Steel IBC	Greenhouse gas (GHG) emissions of reusable steel drums are 64-66% lower, 9% for reusable plastic drums (polyethylene), and 69–71% for steel IBC (Intermediate Bulk Container) crates. Also, lower footprints in other categories.	Ernst and Young (2015)

	Drums for chemicals	Compared single-use fibre drum and a reusable steel drum for the transport of chemicals, showing that the reusable system is environmentally more attractive.	Raugei et al. (2009)
	Beer keg vs. bottle	Beer in keg causes a lower environmental impact along the life cycle than beer in bottles.	Cordella et al. (2008)
	Food (catering)	Evaluation of the environmental impact of a reusable packaging system for a regional catering company showed that the reusable system was beneficial compared to the current single-use system.	Accorsi et al. (2014)
	Crates (for loaves of bread)	Reusable plastic crates for the transport had a better environmental performance than single-use cardboard boxes, though an effective recycling system can also improve performance, dependent on transport impacts and logistics.	Koskela et al. (2014)
	Pallet or crate for small yoghurt packs	Compared wooden pallet (and cardboard boxes) for transportation of consumer yoghurt packages with a plastic reusable packaging system. The reusable system has a lower environmental impact than the wooden pallet, because it is lighter in weight, has more reusable parts and can transport more yoghurt pots per trip. It has a long service life and is virtually fully recyclable.	Lee and Xu (2004)
	Cardboard boxes for fruits & vegetables	Compared corrugated cardboard boxes with reusable plastic packaging systems to distribute fruit and vegetables. Environmental impacts are primarily dependent on the energy to make the materials and transport. Over transport distances of (one way) 1200 km, the single-use cardboard box was preferable.	Levi et al. (2011)
	Crates for automotive parts in internal supply chain	Evaluated impacts of Volvo's internal transport system for automotive parts that uses reusable crates. It found that geographical distances and fill rates were most influential in determining impacts and that geographically long supply chains or low fill rates can tip the balance, and make single-use systems more attractive.	Pålsson et al. (2013)
	Plastic crates	Reusable plastic crates for vegetables and fruits were already environmentally beneficial after reusing the crate three times. Crate manufacturing is the dominant impact until 20 trips.	Tua et al. (2019)
	Display trays for fruit & vegetables	Compared reusable plastic containers to single-use display-ready corrugated board trays for vegetables and fruits distribution, for 10 produced items. Reusable plastic containers require 39% less total energy, produce 95% less total solid waste and generate 29% less total greenhouse gas emissions.	Singh et al. (2006)
B2B/B2C	Thermal packaging for biologic/ Pharmaceuticals	Compared single-use insulated containers to reusable vacuum-insulated packaging. Reusable packaging has a much lower environmental footprint (75% in global warming potential (GWP), 60% in eutrophication and 95% reduction in waste).	Goellner and Sparrow (2014)
B2C	Bottles	Refillable bottles emit less greenhouse gas emissions than one-way bottles. The usage of refill systems has to be deeply analyzed to estimate the number of refills and transport distances, which allows maximizing its environmental benefits.	Simon et al. (2016)
	Soft Drink and Water Bottles	The study compared refillable plastic bottles, improved refillable bottles and single-use bottles. For virtually all impact areas, refillable bottles demonstrate a better environmental performance than single-use bottles, even when the single-use bottle uses 50% recycled material.	Stajcer et al. (2001)

Coffee cups	Reviewed various studies on reusable and disposable coffee cups. Results depend strongly on assumptions in the study. Disposable cup scenarios often do not account for film sleeves, lids, printing, and use conservative shipping weights and distances, reflecting a best-case scenario. Impact for reusable cups will decrease as the electricity mix becomes less CO_2-intensive and dishwashers get more efficient.	Woods and Bakshi (2014)

Screening Criteria 1

In consideration of the above issues and the characteristics of reuse and refill, the following questions might be useful:

- **Will collection, return transportation, and cleaning of reusable packages increase the use of fossil energy or strain a water scarce region compared to the incumbent system (e.g., single use system)?**

Reusable systems inevitably introduce new handling and processing stages. It is important to give these careful consideration.

Screening Criteria 2

- **Does the material (plastic or non-plastic) used for the reuse scheme have a robust recycle market or viable compost solution?**

In other words, what will happen to the reusable package/container/product at the end of its useful life? Will it also become waste, or can it be recycled?

Screening Criteria 3

- **What is the break-even number of reuses where total energy use and GHG emissions are reduced versus the single use incumbent?**

This is a question that developers should be able to answer. It should take a life-cycle approach, accounting for impacts not just in the product's manufacturing, but throughout its lifecycle including return transportation, washing/sanitizing, etc.

Screening Criteria 4

- **How will performance of the reuse scheme change when renewable energy is widespread and commonplace?**

It is possible that a reuse scheme will increase energy consumption of supplying the "function" (packaging, product delivery, etc.) relative to the single-use incumbent. An important follow-up question may then be to consider how this scenario will change as decarbonization of our energy sector continues, and what the focal firm is doing to support and encourage this transition to green energy.

Sources of Information

Companies should have a comprehensive description of their reuse system in their sustainability or business plan. Information is often available on their websites and should be included in product press releases. In early stages, publicly available information may only include assumptions and brief description of their reuse system. In addition, a review of the academic literature may reveal an LCA or other study of a similar product that offers insight into break-even re-uses and parameters critical to performance.

4.1.2. Alternative materials

Basis

Here, we consider "alternative materials" to include using any materials to replace conventional plastics while maintaining an equal or better quality. Generally, these alternatives include natural polymers or materials such as wood, cotton or aluminum. Bio-based materials have the *potential* to be renewable resources and biodegradable, but both claims should be carefully assessed. The regeneration rate of bio-based materials is also important: can production keep pace with demand? Abundance is an important consideration for all materials, as are the intrinsic properties necessary to fulfill a function. Intrinsic properties include:

- chemical resistance
- physical resistance
- thermal resistance
- liquid permeability
- thermal plasticity
- flexibility
- ageing speed

Compostability

Compostable polymers - bioplastics that degrade through digestion by microorganisms - may be seen as an attractive solution to plastic waste. It is important to recognize, however, that often very specific conditions are required to promote this degradation. Composting standards can be divided into industrial composting and home composting, and refer to both composting conditions and composting time.

Table 3. Useful definitions when considering alternative materials (adapted from (United Nations Environment Programme 2017).

Term	Definition
Degradation	The partial or complete breakdown of a polymer due to some combination of UV radiation, oxygen attack, biological attack and temperature. This implies alteration of the properties, such as discoloration, surface cracking, and fragmentation
Biodegradation	Biologically-mediated process involving the complete or partial converted to water, CO2/methane, energy and new biomass by microorganisms (bacteria and fungi).
Compostable – industrial	Capable of being biodegraded at elevated temperatures under specified conditions and time scales, usually only encountered in an industrial composter (standards apply)
Compostable – domestic	Capable of being biodegraded at low to moderate temperatures, typically found in a domestic compost system

In consideration of the above issues and the characteristics of alternative materials, the following questions might be useful for the evaluators:

Screening Criteria 5

- **For compostable materials, what are the required composting conditions for compostable materials?**

A home composting designation may have advantages over an industrial composting designation as less specific conditions (e.g., temperature) are required. Some composting certifications are based on theoretical performance and do not require demonstration under real world conditions.

Screening Criteria 6

- **For bio-based materials, is the biomass sourced from a demonstrated regenerative and sustainable production process? Will this production compete with other critical land uses?**

According to the basic concepts of sustainable development, consumption of renewable resources need to be slower than its regeneration rate. Further, evolving agricultural practices that focus on soil health, biological processes, and minimal industrial inputs (commonly called "regenerative agriculture") are more likely to minimize environmental impact and result in net carbon sequestration. In addition, consideration of land use competition is warranted. For example, crop production that is designated for bio-materials could compete with food production for land use, resulting in increases in food prices. Added competition for land can result in direct or indirect (i.e., through market pressure) land use change (e.g., cutting down rainforest) which can detrimentally impact biodiversity and also cause significant GHG emissions.

Sources of Information

This will depend on whether the innovation is a new application of an existing material or the invention of a new material. If it is an existing material, information on the material's properties, environmental impacts, and safety can likely be obtained from the manufacturer and academic literature. Environmental information regarding new materials is more difficult and may require estimating impacts using surrogate materials that have similar compositions and production processes.

4.1.3. Innovative design

Basis

This is a fairly broad category for innovations that reconsider the fundamental design of a product or service in order to reduce or eliminate the use of plastics, or to dramatically alter the way plastic waste is conceived or handled. These could be personal or home care products such as toothpaste or mouthwash tablets (eliminating the need for toothpaste tubes or mouthwash bottles) or business models that replace selling a product with providing a service, such as music or video streaming (replacing sales of CDs and DVDs).

In such cases, the environmental performance of the new design relative to what it is replacing may not be obvious: impacts can easily shift to a different stage of the life cycle (e.g., from material manufacturing to transportation) or to a different impact category (e.g., from eco-toxicity to GHG emissions). An LCA study comparing the new design with the incumbent product/service will offer valuable perspective.

Short of a full LCA, useful Life Cycle Design guidelines and principles have been developed using life cycle thinking and industrial ecology concepts. These are best implemented in early stages of the redesign process and fully incorporated into the product/service development. A summary of some of these guidelines can be found in Box 1.

Screening Criteria 7

- **Does a comparative LCA demonstrate performance advantages over the status quo?**

See LCA section for additional guidance on evaluating and interpreting LCA.

Screening Criteria 8

- **Are life cycle design principles and guidelines generally followed?**

The principles listed in Box 1 will serve as an excellent starting point for designers aiming to improve the environmental performance of their product/service life cycle.

Sources of Information

Ask the focal firm if they have or intend to conduct an LCA. Alternatively, ask if they are familiar with LCAs conducted on similar products/services: these may offer insight into the parameters or life cycle stages that are important in determining performance. Inviting the focal firm to demonstrate how they do (or intend to) implement life cycle design principles will likely be the most productive means of evaluating this criteria.

Box 1. Life Cycle Design principles

Life cycle design involves applying and incorporating life cycle thinking to the overall design process. This means considering the upstream and downstream influences and impacts of a product or service: from the extraction and processing of materials and fuels required to the operation or use of the product or provision of service, through to the disposal of materials or waste at the end of use. The aim is to decrease the burden or impact on the environment of the final designed product/service.

Life cycle design, sometimes referred to as life cycle engineering, emerged in the mid-1990s alongside developments in life cycle assessment and other industrial ecology concepts. The principles and strategies listed below date from these early developmental days, but directly reflect many of the principles now forwarded under frameworks such as circular economy (see Box 5). Additional guidance for implementing these principles can be found in the original references.

Environmental principles and criteria for Life Cycle Design (adapted from (Behrendt et al. 1997))

- Achieving environmental efficiency / optimal function
- Saving resources
- Using renewable and sufficiently available resources
- Increasing product durability
- Designing for product reuse
- Designing for material recycling
- Designing for disassembly
- Minimizing harmful substances
- Developing environmentally friendly production
- Minimizing environmental impact of product in use
- Using environmentally friendly packaging
- Implementing environmentally friendly disposal of non-recyclable materials
- Implementing environmentally friendly logistics

Table 4. Life Cycle Design strategies (adapted from (Keoleian and Menerey 1994)).

Product life extension	• Extend useful life • Make appropriately durable • Ensure adaptability • Facilitate serviceability by simplifying maintenance and allowing repair • Enable remanufacture • Accommodate reuse
Material life extension	• Specify recycled materials • Use recyclable materials
Material selection	• Substitute materials • Reformulate products
Reduced material intensity	• Conserve resources
Process management	• Process substitution • Process energy efficiency • Process materials efficiency • Process control • Improved process layout • Inventory control and material handling • Facilities planning • Treatment and disposal
Efficient distribution	• Choose efficient transportation • Reduce packaging • Use lower impact/reusable packaging
Improved management practices	• Use office materials and equipment efficiently • Phase out high-impact products • Choose environmentally responsible suppliers and contractors • Label properly and advertise demonstrable environmental improvements

4.1.3.1. Recycling and energy recovery

Plastic recycling is the process of recovering and reprocessing waste plastic into a new (secondary) material that can be used in the production of new components and products (Hahladakis and Iacovidou 2019). After recovery, plastic recycling can be separated into four possible processing pathways (see Figure 2):

- Primary Recycling (Re-extrusion)
- Secondary Recycling (Mechanical Recycling)
- Tertiary Recycling (Chemical or Feedstock Recycling)
- Quaternary Recycling (Energy Recovery)

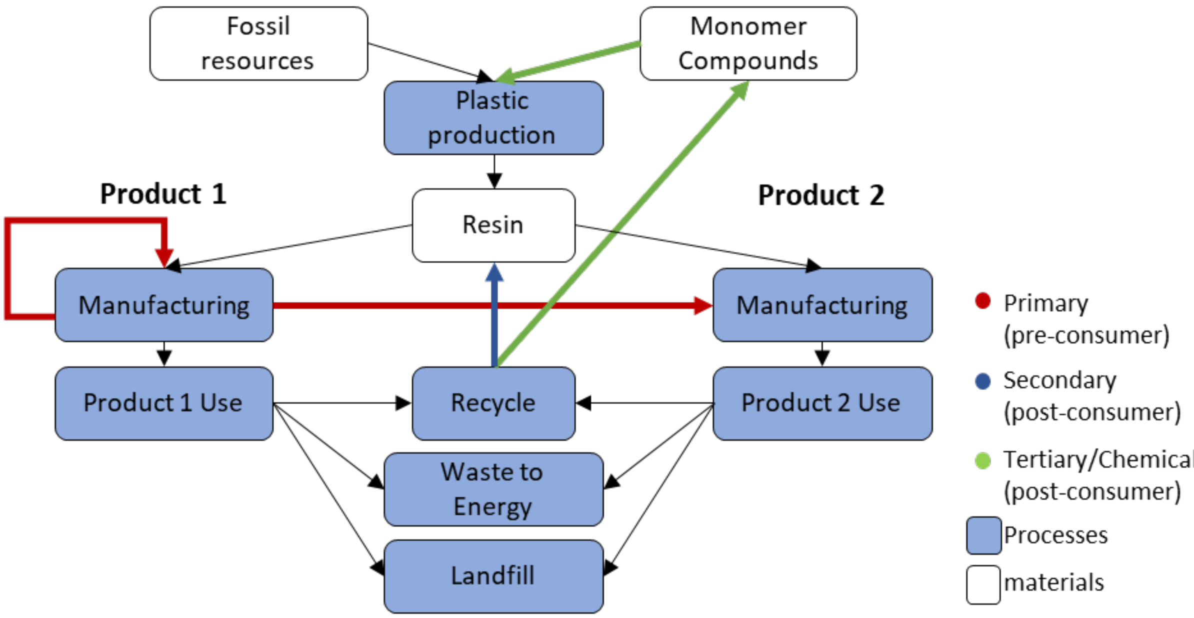

Figure 2. Plastics value chain, differentiating recycling pathways.

Primary recycling is usually managed within the post-industrial or pre-consumer waste stream as a very clean feedstock, with only minor processes (trimming, grinding) required due to the polymer homogeneity. This primary recycling market is quite mature, so in this tool we will only consider post-consumer plastic waste (PCPW) treatment (secondary, tertiary, and quaternary recycling).

The waste management hierarchy shown in Box 2 indicates the conventional preferences in managing plastic waste, including preference of mechanical and chemical recycling over energy recovery. Novel innovations may present opportunity to question this hierarchy, but it offers initial guidance.

Box 2. Plastic waste management hierarchy

The inverted triangle in the figure below is a common hierarchical structure in sustainable materials management (U.S. EPA). It has been applied as a rule-of-thumb consideration of the preferential treatment of many types of waste, including food, and in this case, plastic. In all cases, the widest portion of the triangle positioned at the top indicates preference to efforts that avoid or reduce waste altogether: these intuitively offer the greatest benefit (least harm to the environment) from a life cycle perspective. At the bottom of the triangle, and least desirable in the case of plastics, is leakage into the natural environment where plastics can negatively impact terrestrial and marine ecosystems. Above leakage is loss to landfill, which represents a permanent loss from our technical economy (for the foreseeable future, at least, until landfill mining becomes economically viable). In the middle are the possible recycling pathways considered here, with quaternary recycling (incineration or energy recovery) being a last resort effort to recover value from waste plastics. Mechanical recycling is currently preferred over chemical recycling as it typically is less energy intensive, but innovations in chemical processing could change this. Mechanical recycling is currently burdened with the complications associated with separating a very diverse plastics waste stream, with impurities often leading to lower quality secondary material and thus downcycling (reduction in material value relative to the virgin material).

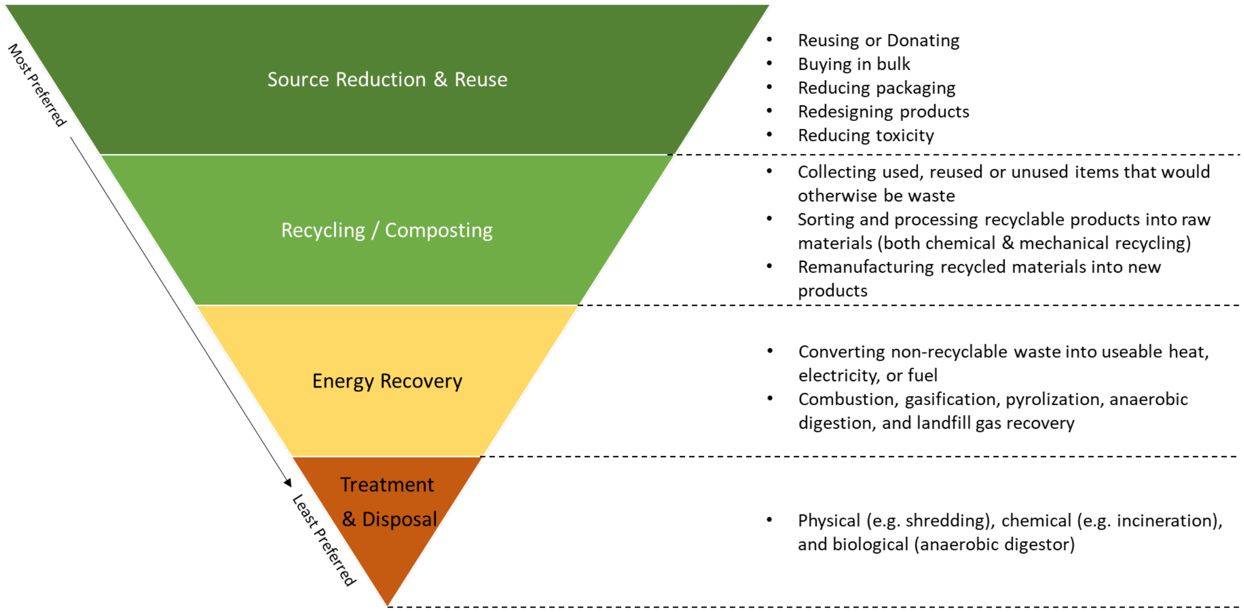

Figure 3. Plastic waste management hierarchy, demonstrating the preference of avoiding waste through prevention, reduction and reuse over all recycling forms, and incineration (quaternary recycling or energy recovery) as a last resource preferred only above land.

4.1.3.2. Mechanical Recycling

Basis

Ultimately, a recycling process must yield a secondary product that is marketable, and to be truly sustainable, it should displace the use of primary (virgin) materials. Barriers to such displacement include material quality (intrinsic properties) but also price/cost. Efficiencies and conversion rates not only drive the amount of material that is converted (and therefore 'recovered') but they also typically have a strong influence on the overall environmental performance of a process.

Mechanical recycling involves sorting plastic waste of a similar chemical structure or resin type, and then processing them into secondary raw materials. In a recent review, (Hahladakis and Iacovidou 2019) summarize the challenges of recycling post-consumer plastic waste, with examples shown in Figure 4. Each of these stages include unique challenges and therefore opportunities for innovation and improvement. As they are commonly separated industries, the sorting and mechanical processing stages are considered independently below.

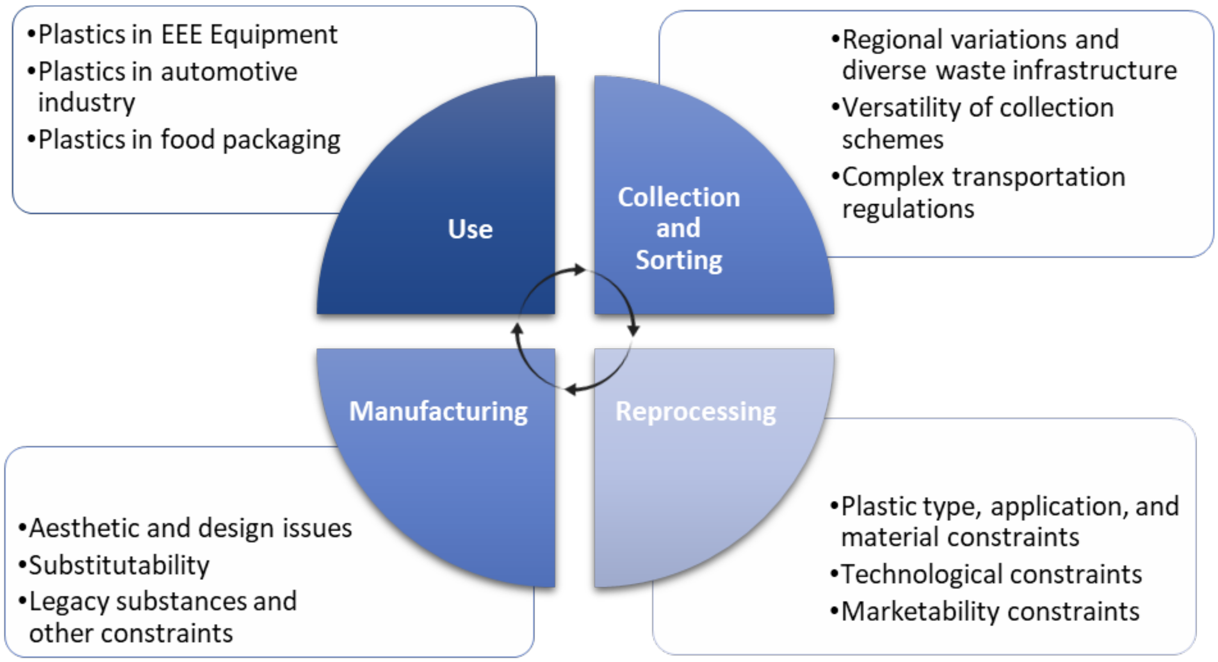

Figure 4. Examples of challenges encountered in the plastics value chain which impact mechanical recycling (adapted from (Hahladakis and Iacovidou 2019)).

Recycling is also commonly divided between "closed-loop" and "open-loop" processes. Closed loop recycling involves recycling a product back into the same product (e.g., PET bottle becomes a new PET bottle). This is commonly seen as preferred over open-loop recycling (downcycling a product/material into a lower quality secondary material/product) as it is assumed to retain more value. Some question the value of this distinction from a sustainability perspective, however, as there isn't an inherent preference: what matters is the relative difference in environmental impact between obtaining the secondary (recycled) material (i.e., the impact of the recycling process) and the environmental impact of providing primary (virgin) material(Geyer et al. 2016).

Screening Criteria 9

- **What is the scalability / efficiency / conversion rate of the innovation compared to existing systems?**

Screening Criteria 10

- **Is the overall waste treatment capacity improved (e.g., in tons / unit time)?**

Screening Criteria 11

- **How much additional collected material can be expected to become utilized/ utilizable recycled polymer?**

4.1.3.2.1. Mechanical Recycling: Sorting

Basis

Mechanical recycling requires polymer resins to be separated and processed independently; however, polymeric resins may be combined in products (e.g., multi-layered films) and collection infrastructure, including consumer behavior, has developed around a mixed waste stream (all plastics, and often all "recyclable waste" collected together). This introduces the need to sorting and separation methods, which historically has presented a cost (and sometimes technological) bottleneck. Ongoing technological improvements increase our ability to efficiently separate plastics from other materials, and separate types of plastics. Sorting efficiency, a critical metric of performance for new sorting technologies, is often measured by:

- # of pieces / unit time
- Different types of polymer to be treated / unit time
- Sorting loss %, or error rate

Some sorting processes may require consumer behavioral changes, adjustments to municipal collection techniques, adherence to industry standards (e.g., in relation to label material types) or even governmental regulations in order to be successful. While certainly not impossible, these introduce added risk.

Screening Criteria 12

- **How is the innovation unique compared to the incumbent collection / sorting systems?**

Since there exists various kinds of plastic collection and sorting systems, it is important to identify the key characteristics making the innovation unique. Some examples might be sorting more than three types of polymers or using intelligent tracking systems. The focal firm should be able to identify the limitations of traditional methods and how their innovation overcomes these limitations.

Screening Criteria 13

- **What is the targeted waste stream?**

Current plastics recycling markets are dominated by PET, PE, and PP; because there is high demand for secondary material of these resin types, they represent the highest value to material recovery facilities (MRF) and other resin types are lower priority or even primarily considered a 'contamination' in the waste stream. Thus, innovations that focus on identifying and separating resins with lower market value will not only improve the quality of dominant recycled plastic streams but also support the development of new solutions for harder-to-recycle resins.

Screening Criteria 14

- **Is the sorting efficiency improved compared to the incumbent or competing sorting / collection process?**

Sorting efficiency is likely the most influential parameter in determining the environmental performance of a collection and sorting process. Careful consideration needs to be paid to the basis of these efficiencies (how the value(s) are reported) as they may mask improper comparisons with the status quo. It will be important to consider not only sorting rate/efficiency but also the number of resins that are being sorted.

Screening Criteria 15

- **Are there any social or behavioral changes required to complement the new sorting process? What efforts will be made to support this change?**

The need for behavioral and industry standard changes is perhaps an inevitable part of improving the plastic waste management situation, but they are difficult to predict and influence. If an innovation is relying on such a change, what efforts are being made to support it?

Screening Criteria 16

- **Are there any regulatory measures conflicting with this business / service model?**

Investors will need to assure how local or federal regulations on polymer recycling and sorting, collection routes, label and additive standards, etc. will impact the theoretical efficiency and scale of an innovation. The focal firm should provide clear resolutions on these issues.

4.1.3.2.2. Mechanical Recycling: Processing

Basis

Assuming post-consumer plastics are perfectly sorted and lacking contaminants, the principal challenge in mechanically reprocessing plastics is that polymers degrade under certain conditions including heat, oxidation, light, ionic radiation, hydrolysis, and mechanical shear(Ragaert et al. 2017). This typically results in lower quality recycled material, but can also hinder the processing itself. Thermal-mechanical degradation can occur during reprocessing, whereas other forms of degradation typically occur during the lifetime of the product. Contaminants, both designed (i.e., intentionally added such as colors, plasticizers, processing aids, labels, inks) and created (i.e., dirt, residues, incomplete polymer sorting) introduce additional challenges in reprocessing.

Ultimately, a recycling process must yield a secondary product that is marketable, and to be truly sustainable, it should displace the use of primary (virgin) materials. Barriers to such displacement include material quality (intrinsic properties) but also price/cost.

Screening Criteria 17

- **How is the innovation unique compared to the incumbent process?**

The novelty of the new technology should be explained concisely, and its function, performance, advantage, etc. compared to incumbent processes should be identified. These represent important considerations when evaluating differences in environmental performance.

Screening Criteria 18

- **How much of the collected material becomes utilized/ utilizable recycled polymer?**

This basic conversion efficiency of the overall recycling process is likely to be one of the key drivers of environmental performance.

Screening Criteria 19

- **Does the process result in material of sufficient quality, retained intrinsic properties, and durability to supply a secondary material market?**

Consideration of the quality of materials resulting from the processing innovation may offer insight into available markets. Is the material quality sufficient to displace primary (virgin) materials? If quality is reduced, is there a known consistent market for the material? Does this represent the greatest retention of technical value?

Screening Criteria 20

- **Does the processing introduce unique or notable environmental considerations?**

LCA (Section 3.7.2) is the preferred method for evaluating the environmental performance of an innovation relative to the status quo. However, there may be special considerations that demand additional attention: is a solvent or other chemical being used in the process? How is it recovered/disposed? Are there nutrients or other contaminants released to municipal wastewater?

4.1.3.3. Alternative Recycling and Energy Recovery

Basis

Alternative recycling methods include chemical recycling, waste-to-fuel processing such as pyrolysis, and energy recovery through incineration. We consider chemical recycling as any process that chemically modifies a polymer so that it can be reprocessed and remade into new plastic materials. Waste-to-fuel pathways involve chemical modification into a (typically) liquid or gas fuel that can then be used, for example, as a transport fuel (see Figure 5). This is in essence energy recovery, but is of somewhat higher value as liquid or gaseous fuels are more versatile. Traditional energy recovery (waste-to-energy) through incineration is the process of converting municipal solid waste into electricity or steam (energy carriers) through controlled combustion.

Chemical recycling technologies are largely in nascent stages; but to date there are very few examples of processes taken to scale. Given the novelty of these technologies and the diversity of potential pathways, consultation with outside specialists in the chemistry industry may be necessary. Gasification, pyrolysis, and depolymerization processes can convert plastics into raw materials for chemical production and feedstocks for new plastics production as well as fuels. Solvent based processes can be used to dissolve polymers to remove impurities and the polymers filtered out and reconstituted.

Energy recovery – both waste-to-fuel or incineration – should be considered as last resort efforts only when other options for recovering technical value are not available. Conversion of plastics derived from petroleum resources to fuels, however, will generate greenhouse gases upon combustion which is problematic given the climate crisis.

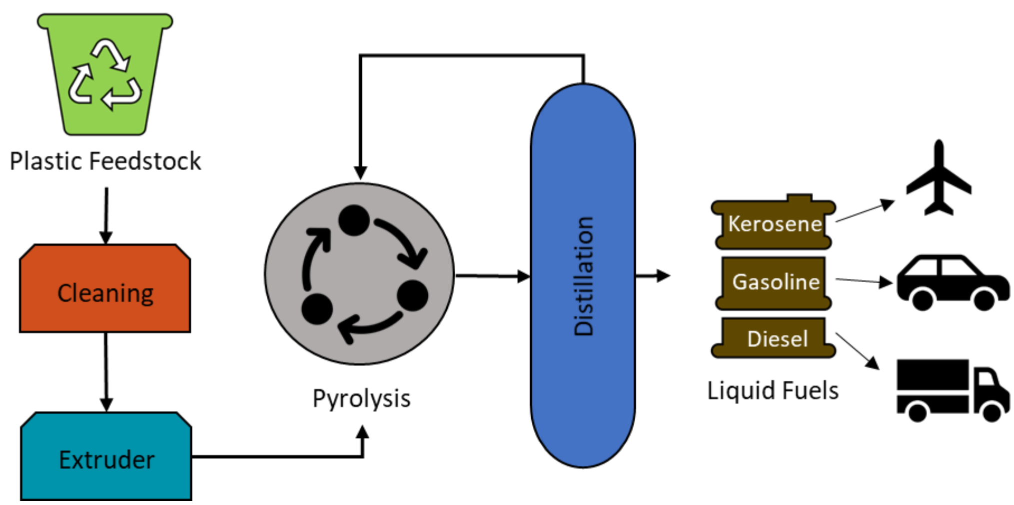

Figure 5. Process flow diagram of a classical pyrolysis plant (adapted from (Ragaert et al. 2017)).

Screening Criteria 21

- **What is the scalability / efficiency / carbon emissions intensity/ conversion rate of the chemical recycling process?**

Efficiencies and conversion rates not only drive the amount of material that is converted (and therefore ‘recovered’) but they also typically have a strong influence on the overall environmental performance of a process. The carbon emissions generated by the chemical recycling process should be compared against the carbon emissions from a process utilizing petroleum or natural gas feedstocks.

Screening Criteria 22

- **Does the sourcing/sorting process assure that energy recovery is the highest and best use?**

As stated before, energy recovery should be the last choice because it recovers the least amount of "technical value" in the material. It is also important to note that combustion of plastics releases the carbon (in the form of CO_2) that otherwise is "sequestered" in the plastic, meaning that it contributes to climate change. Depending on the source of the energy that is being displaced (e.g., the standard electricity grid) this *may* still result in a net reduction in greenhouse gas emissions, but it cannot be assumed.

Screening Criteria 23

- **Is the waste treatment capacity improved (e.g., in tons / unit time)?**

Screening Criteria 24

- **Is the energy recovery rate improved and economical (e.g., in MJ or kWh / ton of waste)?**

4.2. Scale of Potential Impact

This set of guidance criteria helps determine whether or not the innovation will have a significant impact on the plastics waste problem. The magnitude of the waste reduction from the implementation of the innovation relative to the incumbent system is an important evaluation metric. The methods to estimate the scale of potential impact can vary according to different kinds of technologies. The technology specific screening criteria presented in Section 4.1 can also be useful in evaluating the level of waste reduction.

Guidance Criteria 6

- **Does the intervention target a product that is *unnecessary, avoidable, and problematic* (i.e. a high likelihood of losses to natural environments, a difficult to recycle plastic or product, or other high priority waste stream)?**

Basis

The basis for consideration of "sustainability" or environmental impact often is at the product or material level: how does the performance of a product (or innovation) compare with the status quo? This is critical, but it also is important to consider the extent to which a given innovation will *scale* within the broader economy. This requires understanding where and how plastics are used currently (see Box 3), what the targeted market for the innovation in consideration is, the amount of plastic used in that market sector, and how the innovation will reduce that plastic use/waste. This potential scalability will influence not only the overall amount of plastic waste that may be reduced, but – if the innovation proves to be environmentally preferable to the status quo – the absolute benefits to sustainability: greenhouse gas emission reductions, reductions in fossil energy use, etc.

It also is important to recognize that some plastics, for example, those that are particularly difficult to recycle or do not have a developed recycle market, should be prioritized in reduction / elimination. Therefore, an innovation targeting such a plastic may be important even if its potential to reduce overall plastic mass is lower than another.

Interventions targeting the reduction of plastic waste that is more likely to end up as pollution in a natural environment (e.g., plastic shopping bags, convenience food wrappers) may warrant priority, even when the absolute mass of reduction is lower.

Sources of information

Information on plastic use in specific sectors can be extremely difficult to find, especially at more granular market sector levels. Box 4 offers an example utilizing Economic Input/Output accounts. Market analysis reports may also offer insight. In both of these cases, size/scale is based on economic values, and translating this to physical units (mass) can be challenging. Again, one approach is presented in Box 4. Ultimately, however, the goal here is likely coarse (order of magnitude?) estimates that offer some semblance of scale: 100s of tons? 1000s of tons? Millions of tons?

Guidance Criteria 7

- **What is the maximum potential for this intervention to reduce plastic use/waste?**

Basis

The ultimate market success of an innovation/intervention is impossible to predict, but placing some bounds on the *potential* of a given innovation to reduce plastic use and waste – given current usage in the target sector, the displacement offered by the innovation, and anticipated market penetration – can offer important guidance on its effectiveness as a plastic waste reduction strategy.

The basis for consideration of "sustainability" or environmental impact often is at the product or material level: how does the performance of a product (or innovation) compare with the status quo? This is critical, but it also is important to consider the extent to which a given innovation will *scale* within the broader economy. This requires understanding where and how plastics are used currently (see Box 3), what the targeted market for the innovation in consideration is, the amount of plastic used in that market sector, and how the innovation will reduce that plastic use/waste. This potential scalability will influence not only the overall amount of plastic waste that may be reduced, but – if the innovation proves to be environmentally preferable to the status quo – the absolute benefits to sustainability: greenhouse gas emission reductions, reductions in fossil energy use, etc.

Plastic waste reduction can occur through many different approaches and business models; how a given innovation reduces net plastic waste should be clearly demonstrated. This requires a systems-based perspective in order to assure that an apparent reduction in plastic use or waste doesn't result in changes in behavior or performance elsewhere that lead to net *increases*. For example, anecdotal evidence suggests that plastic shopping bag bans could lead to increases in plastic trash bags as the opportunity for shopping bags to serve a second life as trash bags is removed. Reusable cups or containers intended to replace disposable plastic items typically require larger amounts of plastic to be durable: this creates a "tipping point" that often relies on individual behavior to reuse the product a sufficient number of times (and displace enough disposables) so that the net result is a decrease in plastic use.

Box 3. Material flow of plastics in the US

Plastics are ubiquitous in today's society, owing to their versatility, light weight, strength, durability, corrosion resistance, thermal and electrical insulating properties, and relatively low cost. Appreciation of the material flow of plastics – the amount and variety of plastics used in different industrial sectors and how they are disposed at end-of-life – can greatly assist in identifying opportunities for significant reductions in wasted plastics. The figure below illustrates the flow of plastics through the US economy circa 2017, based on an aggregation of best available data (Heller et al. 2020). It offers a sense of scale across polymer types, use sectors and end of life destinations that can provide context and orientation for strategic solutions. Plastic packaging utilizes large quantities of materials in predominantly single-use, ‘disposable’ applications, clearly warranting focused efforts for reductions where possible and coordinated material recovery and recycling solutions implemented throughout design, recovery and reprocessing. However, the material flow presented here reminds us of an important perspective: over two thirds of the plastics put into use in 2017 found applications outside of packaging. These other use sectors introduce unique challenges as well as opportunities, but will also benefit from increased coordination of circular economy thinking between innovation and design and recovery and recycling.

There also are notable gaps in our understanding of the material flow of plastics. Identifying opportunities to improve data access and availability throughout the plastics supply chain will enhance the abilities of innovators and investors to further target plastic waste reduction prospects.

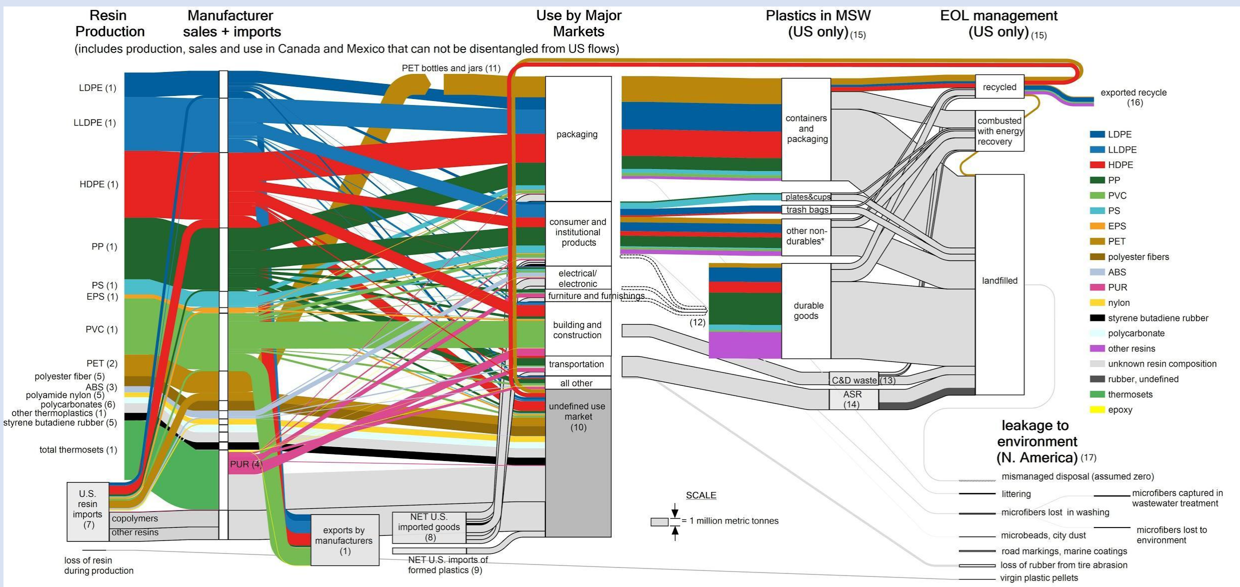

Figure 6. Production, imports, exports, use, disposal and leakage of plastics in the US in 2017. Width of flows scaled to mass (for reference: production of HDPE = 8.576 million metric tonnes). Colors correspond to polymer types (see legend). Numbers in parentheses refer to notes in table 1 of (Heller et al. 2020). Note that the difference in mass between production (left side) and end-of-life (right side) in this 2017 snapshot represents a net addition to in-use stock.

Box 4. Example: Scale of Reduction

Limited data availability often makes it difficult to estimate the potential scale of reduction from a given innovation. We’ve explored innovative approaches to estimating the use of plastics in specific sectors, and therefore the potential to reduce plastic use by displacing its use in that sector. Here we detail one approach based on the US Bureau of Economic Analysis Input/Output Accounts. These data offer a comprehensive picture of the inner workings of the U.S. economy, showing production relationships among industries and commodities, based on economic exchanges. While input-output data are updated each year and provide information on 71 industry categories, detailed benchmark input-output statistics are further subdivided into 405 industries and produced roughly every five years. The detailed data is required for the level of resolution needed here, thus this assessment relies on data from the most recent year available, 2012 (available at: https://apps.bea.gov/industry/xls/io-annual/Use_SUT_Framework_2007_2012_DET.xlsx).

The supply and make tables present the commodities that are produced by each industry. The supply table extends the framework, showing supply from domestic and foreign producers that are available for use in the domestic economy in both basic and purchasers' prices. The use table shows the use of this supply by domestic industries as intermediate inputs and by final users as well as value added by industry. For more information on input-output accounts, see: https://www.bea.gov/resources/methodologies/concepts-methods-io-accounts.

Of interest in this analysis are the plastics-related commodities: "plastics material and resin manufacturing" (BEA Industry Code 325211) and the 10 commodities within "Plastics and rubber products" (BEA IC 326). First the dollar value of plastic resin required as input per dollar of industry output for each of the 10 "plastics and rubber products" can be estimated by dividing the input value by total industry output (in millions of USD), as seen in the following screenshot:

	(from 2012 BEA Supply Use Table)		Plastics packaging materials and unlaminated film and sheet manufacturing	Plastics pipe, pipe fitting, and unlaminated profile shape manufacturing	Laminated plastics plate, sheet (except packaging), and shape manufacturing	Polystyrene foam product manufacturing	Urethane and other foam product (except polystyrene) manufacturing	Plastics bottle manufacturing	Other plastics product manufacturing	Tire manufacturing	Rubber and plastics hoses and belting manufacturing	Other rubber product manufacturing
	industry code		326110	326120	326130	326140	326150	326160	326190	326210	326220	326290
A	Plastics material and resin manufacturing	325211	14,140	6,350	558	2,262	756	4,843	19,319	73	163	306
B	Total industry output (basic value)	T018	39,372	15,421	3,543	8,303	9,437	12,322	83,550	21,030	5,277	18,059
	resin fraction of total industry output (calculated)	(A/B)	0.359	0.412	0.157	0.272	0.080	0.393	0.231	0.003	0.031	0.017

Next, the mass of resin used per industry output (in dollars) of each "plastic material" can be estimated using a price for plastic resin to convert the dollar ratio generated above into physical units of plastic used. Here, we've relied on historical market data from The Plastics Exchange website: http://www.theplasticsexchange.com/Research/WeeklyReview.aspx.

Weekly summary reports for the first 6 months of 2012 were downloaded, a weighted average price (weighted by quantity sold each week) for each resin was calculated, and then – because resin type is not detailed in the I/O tables – a weighted average price across resin types (again, weighted by quantity sold for each resin over the 6 months) was calculated. The "spot" price from the market summary reports was used. This resulted in an average price of $0.67/lb ($1.56/kg), which was divided into the "resin fraction of total industry output" to arrive at kg plastic resin per $ total industry output for each of the "plastic material" commodities.

This result can then be multiplied by the $ of plastic material commodities used in other industries/sectors to offer a coarse estimate of the amount of plastics used in that industry. For example, if we were interested in knowing the plastics used in food service and drinking places (BEA Industry Codes 722110, 722211, 722A00):

	(from 2012 BEA Supply-Use Table)	Full-service restaurants	Limited-service restaurants	All other food and drinking places
BEA industry codes	Commodity Description	722110	722211	722A00
		[millions of US dollars]		
326110	Plastics packaging materials and unlaminated film and sheet manufacturing	113	67	4
326120	Plastics pipe, pipe fitting, and unlaminated profile shape manufacturing	138	125	28
326130	Laminated plastics plate, sheet (except packaging), and shape manufacturing	10	29	5
326140	Polystyrene foam product manufacturing	213	2520	142
326150	Urethane and other foam product (except polystyrene) manufacturing	511	1423	327
326160	Plastics bottle manufacturing	4	21	1
326190	Other plastics product manufacturing	460	641	67
326210	Tire manufacturing	84	38	7
326220	Rubber and plastics hoses and belting manufacturing			
326290	Other rubber product manufacturing	0	60	12
		metric tonnes plastic		
326110	Plastics packaging materials and unlaminated film and sheet manufacturing	2.60E+04	1.54E+04	9.19E+02
326120	Plastics pipe, pipe fitting, and unlaminated profile shape manufacturing	3.63E+04	3.29E+04	7.37E+03
326130	Laminated plastics plate, sheet (except packaging), and shape manufacturing	1.01E+03	2.92E+03	5.04E+02
326140	Polystyrene foam product manufacturing	3.71E+04	4.39E+05	2.47E+04
326150	Urethane and other foam product (except polystyrene) manufacturing	2.62E+04	7.29E+04	1.68E+04
326160	Plastics bottle manufacturing	1.01E+03	5.28E+03	2.51E+02
326190	Other plastics product manufacturing	6.80E+04	9.48E+04	9.91E+03
326210	Tire manufacturing	1.86E+02	8.44E+01	1.55E+01
326220	Rubber and plastics hoses and belting manufacturing			
326290	Other rubber product manufacturing	0	6.50E+02	1.30E+02
	total	195,828	664,056	60,600
	total (plastics only)	195,641	663,321	60,455

Disregarding the "rubber" plastic material commodities, summing the values in light pink in the above screenshot amounts to ~0.9 million metric tons of plastic utilized in food service and drinking places in 2012. This is ~1.5% of the total plastics used in the US.

Even though this approach relies on a number of simplifications, such as averaging resin prices, it offers a coarse scaling of the plastics used in specific sectors/industries and therefore provides some insight into the potential reductions from innovations.

4.3. Technology and Market Readiness

This set of guidance criteria helps assess the overall viability of the innovation, both in terms of whether its technical attributes are of sufficient quality to make it competitive within existing markets and whether there are potential logistical or behavioral barriers that need to be addressed. For example, even if a material *can* be recycled, there must be recycling infrastructure in place in order achieve any benefit. Similarly, consumers must actually participate in plastic return programs for extended producer responsibility initiatives to work. Therefore, it is important to evaluate how potential business plans will reduce logistical and/or behavioral barriers in order to realize the benefits of an innovation as designed.

Guidance Criteria 8

- **Guidance Criterion: Is the technical quality of the innovation sufficiently competitive?**

Basis

Consideration of the quality of materials resulting from the processing innovation may offer insight into available markets. For example, is the material quality of a recycled material sufficient to displace primary (virgin) materials? If quality is reduced, is there a known consistent market for the material? Does this represent the greatest retention of technical value?

Technical quality for products still in development may not yet be known. The following section discusses how various stages of technical maturity may impact overall levels of uncertainty on this criterion, as well as several others.

4.3.1. Technology Maturity

The amount of information available about a product/innovation will typically depend on its maturity level. In other words, with innovations in early research and development stages, information on sustainability performance will be limited or speculative; for innovations that have already been introduced into a market, even at a limited deployment, we can reasonably expect there to be additional information about sustainability performance. Here, we introduce an existing technology readiness level scale as a tool to determine whether "growth stage" criteria are appropriate to consider or expect.

Technology Readiness Level (TRL) (Figure 7) is an indicator of the maturity level of a technology. Whether the innovation is in **the early, growth, or mature stage** will offer guidance on the type of information it is reasonable to expect.

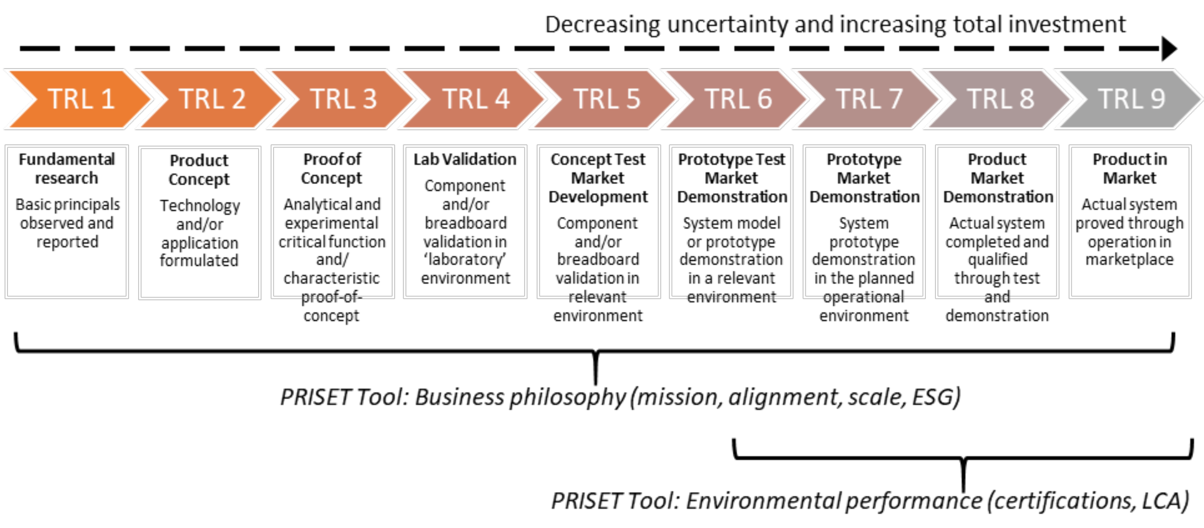

Figure 7. Graphic representation of technology readiness levels.

Every innovation in the research phase is among the early stage, and every innovation in the deployment phase is among the growth stage. There might be some overlaps under the development phase, but the break point shall be whether the innovation is still in lab or pilot project, or at an operational scale in a more realistic environment.

One of the challenges for **early-stage** companies is that their innovation or technology may be less defined, and lack of data, lack of incumbents against which to compare, and uncertainty regarding deployment in market conditions will make it difficult to offer a retrospective assessment based in experience.

For **mature companies** whose technology is commercialized, certifications, life cycle assessments, or other quantitative analyses should be possible and offer more direct assessment of environmental impacts as well as performance relative to incumbent or competing technologies/products/services.

Note that the maturity level separation is offered only as a guide, not a prescript. Evaluation of early-stage companies may be limited by availability of data or information, but further evaluation (i.e., **Environmental Performance** criteria) is always encouraged when possible.

4.3.2. Infrastructure

Guidance Criteria 9

- Does the required physical and/or logistical infrastructure exist to support adoption of the innovation? What infrastructure changes may be required?

Basis

In order for an innovation to be successful and achieve its full impact potential, the required physical and logistical infrastructure must be in place. For example, many municipal recycling systems are unable to process certain kinds of plastic. Simply being "recyclable" - capable of being recycled - may not be enough if the infrastructure to collect and process and the market for secondary (recycled) materials don't exist.

Even in a product can be recycled from a technical perspective, it may not be recycled in practice. "End of life" means how a product is managed or disposed after it is no longer used/useful to the consumer. Careful attention is required through product design to assure that the embedded materials can be easily reused or recycled rather than disposed in landfill. For product take back and/or reuse innovations, the appropriate physical and logistical systems must be in place for consumers to return items, and product inventory to be tracked, reclaimed, cleaned or refurbished, and sent back into use. Appropriate quality assurance/quality control mechanisms should also be considered to take into account potential performance degradation over time.

4.3.3. Market Readiness

Guidance Criteria 10

- Are there social or behavioral changes required for the innovation to be effective? What efforts will be made to support this change?

Basis

Similar to infrastructure availability, innovations will need to be socially acceptable and culturally appropriate in order to be successful. Many innovations will require consumers to change their behavior in some way. Municipal recycling efforts required a good deal of consumer education to help households understand how to participate. Innovations that require active consumer participation will likely require thoughtful efforts to help support success of the innovation. These may include education campaigns, incentive or penalty structures, ensuring user-friendly physical and virtual infrastructure, and other mechanisms to support participation.

This is a fairly broad category for innovations that reconsider the fundamental design of a product or service in order to reduce or eliminate the use of plastics, or to dramatically alter the way plastic waste is conceived or handled. These could be personal or home care products such as toothpaste or mouthwash tablets (eliminating the need for toothpaste tubes or mouthwash bottles) or business models that replace selling a product with providing a service, such as music or video streaming (replacing sales of CDs and DVDs).

In such cases, the environmental performance of the new design relative to what it is replacing may not be obvious: impacts can easily shift to a different stage of the life cycle (e.g., from material manufacturing to transportation) or to a different impact category (e.g., from eco-toxicity to GHG emissions).

5. Part C. Systems-Level Sustainability Assessment

This set of guidance criteria helps evaluate the sustainability of an innovation, with an emphasis on environmental impacts. Using tools such as life cycle assessment and circular economy principles, the criteria help identify the benefits as well as potential tradeoffs that may be associated with the innovation. Estimating the environmental impacts of new innovations is rarely a straightforward process. Additional guidance is provided for evaluating the quality of a life cycle assessment, if available.

5.1. Circular Economy

The Circular Economy (CE) concept offers an accessible and engaging framework for implementing many of the ideas that have been developing along with the field of industrial ecology for multiple decades. Some elements of CE may also be included in ESG reporting, although it is broken out specifically due to its prevalence in overall discussions related to the plastics sector. Box 5 provides background on CE. Here we discuss how the concepts of CE can be used to evaluate whether a new innovation is on the proper path to improve sustainability.

While CE is, in part, a paradigm for reducing waste, it is important to note that having circular attributes does not necessarily equate to enhanced sustainability performance (Miller 2020). Numerous metrics to evaluate CE are being developed to evaluate various aspects of the concept. Guidance as to which metrics are most appropriate is limited and some demonstrations point to the fact that these CE metrics do not always correlate with systems-based sustainability performance results from tools like life cycle assessment (Lonca et al. 2018; Walker et al. 2018).

Guidance Criteria 11

- Does the innovation build upon Circular Economy Principles?

Although developed for **plastic packaging**, the six commitments defined by the Ellen MacArthur Foundation in the New Plastics Economy Global Commitment (New Plastics Economy Global Commitment 2019) can be used to guide circular economy thinking more broadly.

1. Elimination of unnecessary plastic packaging through redesign, innovation, and new delivery models is a priority.

In general, can decisions made early in the development process reduce the use of plastics when compared to standard actions? Can a single part replace several parts? Can that part be made of plastic with a high recycle value? Can a composite be replaced by a single material? Can a small tweak enable easy disassembly and repair? Can initial design parameters allow the use of recycled resin?

An example of eliminating unnecessary plastic packaging is concentrating cleaning products in smaller packages by eliminating water in the product. Product that is sold as a concentrate is often several times smaller physically and weighs less than its diluted counterpart, saving plastic packaging and emissions on shipping.

Another example of elimination of packaging is Algramo found at https://www.algramo.us/. Algramo is a smart cleaning product dispensing system that allows customers to bring their own refillable packaging and only purchase the amount of cleaning product they need without paying for the packaging.

2. Reuse models are applied where relevant, reducing the need for single-use packaging.

A reused package functioning for secondary use cannot be considered as reusable packaging, e.g. the use of a package as a pen-holder or as decoration cannot be qualified as reuse. The end of life management of the reusable packaging should be circular: i.e. refurbished for further reuse or recyclable into a valuable recycle stream. Can the reuse cross markets? Can a B to B shipping crate be designed to end life as part of a building or civil engineering structure?

An example of a reuse model is Coca-Cola refillable soda bottles (Packaging Europe, 2020). When customers purchase Coca-Cola products in a reusable bottle, they pay an indirect deposit in which they receive a discount on their next purchase. Coca-Cola collects used bottles from retailers, and then cleans and refills them to be put back on shelves. The soda bottles are made of 100% PET and are fully recyclable at end of life.

3. All plastic packaging is 100% reusable, recyclable, or compostable.

Early design decisions can drive the choice of materials. Efforts should be made to use components made from single materials where these materials have value in the recycle market. It should be noted that compostability is as much a process as a material. Materials that can compost at low heat (i.e., in a backyard) are a small fraction of "compostable materials" most of which need a high heat industrial composting process.

An example of material selection for sustainable packaging is Papr deodorant (Papr). Papr deodorant challenges the traditional plastic deodorant packaging with a full recyclable or biodegradable packaging consisting of paper, a cornstarch lining, and soy ink.

4. All plastic packaging is reused, recycled, or composted in practice.

Point 3 ensures that the materials are recyclable. Point 4 ensures that the reverse supply chain, processing and market realities are demonstrated in practice. Pay attention to the environment or human health impact from the recycling process, e.g., the use of landfill pickers or unregulated de-constructors.

5. The use of plastics is fully decoupled from the consumption of finite resources.

The theoretical goal of the circular economy is to decouple economic growth from resource extraction. Consider how the focal firm is moving in this direction. Special attention should be paid to rebound (Zink and Geyer 2017) where the impact of a circular economy intervention increases the extraction of virgin materials.

6. All plastic packaging is free of hazardous chemicals, and the health, safety, and rights of all people involved are respected.

Sources of Information

Circular economy has its roots in the field of Industrial Ecology (see Box 5) and draws on concepts and principles from this academic field. Ellen MacArthur Foundation has played a key role in promoting Circular Economy and has published several reports which are accessible from the foundation's website: https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy.

Case studies that apply the circular economy paradigm to existing and emerging products and technologies are growing in the academic literature and may offer valuable reference. Ultimately, information on a product's circularity may require directed communications with the focal firm.

Box 5. Circular Economy

In its most basic sense, the circular economy (CE) stands in contrast to the historically dominant “linear economy,” one in which product life cycles typically follow a “take-make-use-dispose” pattern. Yet, the development of the CE concept has occurred over a diversity of disciplinary perspectives, resulting in broad interpretations and differing central tenets. Many have recognized CE as an umbrella concept (CIRAIG 2015; Blomsma and Brennan 2017; Homrich et al. 2018) that includes lowering material input and minimizing waste generation (EASAC 2016; EEA 2016) in order to decouple economic growth from natural resource use (EASAC 2016; Cullen 2017; Pauliuk 2018). Kirchherr et al. review 114 identified definitions of CE and arrive at the following synthesized definition:

> CE is defined as “an economic system that replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations” (Kirchherr et al. 2017).

In many ways, CE represents a “popularization” of concepts and ideas that have been developing along with the field of industrial ecology for multiple decades, and through frameworks such as life cycle assessment, life cycle design (Keoleian and Menerey 1993), green engineering principles (Anastas and Zimmerman 2007), design for environment principles (Telenko et al. 2008), and others.

Common strategies of CE include preserving the function of products or services (sharing platforms, Product-Service Systems, multifunctionality); preserving the product itself (durability, reuse, restore, refurbish, remanufacture); preserving product components (reuse, recovery, repurposing of parts); preserving materials (recycling, downcycling); preserve embodied energy (incineration, landfill gas capture) (Moraga et al. 2019).

The Ellen Macarthur Foundation has popularized the “butterfly diagram,” shown below, as a representation of the CE. The figure represents many of the “circular” strategies of CE, including preserving the function of products or services (sharing platforms, Product-Service Systems, multifunctionality); preserving the product itself (durability, reuse, restore, refurbish, remanufacture); preserving product components (reuse, recovery, repurposing of parts); preserving materials (recycling, downcycling); and preserving embodied energy (incineration, landfill gas capture). It also captures the importance of CE strategies to incorporate energy sustainability and the transition to renewable energy.

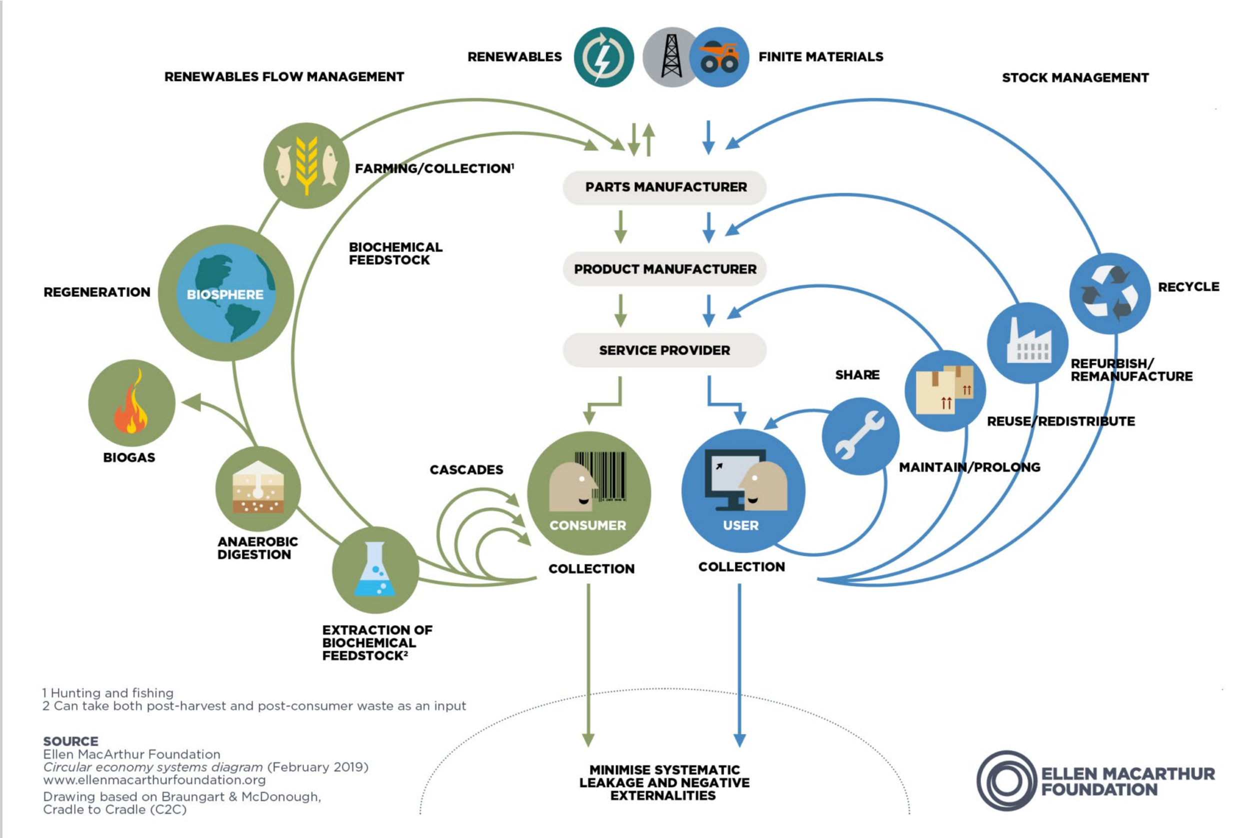

Figure 8. Circular economy representation popularized by the Ellen MacCarthur Foundation, commonly referred to as the "butterfly diagram" (Ellen MacArthur Foundation).

While CE engages a number of critical tenets of sustainability, including decoupling economic growth from natural resource consumption, reducing material inputs, and minimizing waste generation, it is equally important to recognize that CE strategies do not inherently reduce environmental impacts. Dozens of CE metrics have been proposed, ranging in scope and complexity from straightforward recycling rates to combined metrics that integrate mass and time components (Moraga et al. 2019; Parchomenko et al. 2019; Saidani et al. 2019). These metrics offer valuable means of providing rapid guidance and feedback in planning, design and implementation, but are not sufficient by themselves in assessing sustainability performance, and ultimately require system level assessment through tools such as LCA to assure that CE strategies do indeed result in net reductions in environmental impacts.

Examples of Circular Economy concepts:

- Share: Communities have started creating tool-lending libraries. Instead of buying a new tool that one might use only once or twice a year, community members share a set of tools by renting them out from their look tool-ending libraries, just as they might do with books.
- Maintain/Prolong: Steelcase makes durable office furniture that lasts decades. Parts for Steelcase furniture can be replaced individually if worn out, rather than purchasing new furniture.
- Reuse/Redistribute: Loop Packaging replaces single use packaging with reusable and refillable aluminum packaging. Several companies, such as Hagan Das, Clorox, and Seventh Generation are piloting the use of Loop Packaging with their product.

- Refurbish/Remanufacture: Xerox takes back used cartridges and toner containers and remanufactures them into new cartridges ready for purchase and reuse.
- Recycle: PET bottles are recycled into resin which then can be used to re-create new PET bottles.

It is important to note that verification and quantification of the potential sustainability benefits of these circular economy examples compared to single use approaches requires the application of techniques such as life cycle assessment.

Even life cycle assessments, however, are not without limitations. In particular, the impacts of plastic leakage into the environment are not well measured today. Thus, verification and quantification of the potential sustainability benefits must also consider the weaknesses of each technique. It is possible that a reuse scheme will increase energy consumption of supplying the "function" (packaging, product delivery, etc.) relative to the single-use incumbent. An important follow-up question may then be to consider how this scenario will change as decarbonization of our energy sector continues, and what the focal firm is doing to support and encourage this transition to green energy.

Guidance Criteria 12

- **How are materials used for the innovation managed at end-of-life?**

"End of life" means how a product is managed or disposed after it is no longer used/useful to the consumer. Careful attention is required through product design to assure that the embedded materials can be easily reused or recycled rather than disposed in landfill. This includes demonstrating a robust and widespread collection and recycling process for the materials: simply being "recyclable" - capable of being recycled - may not be enough if the infrastructure to collect and process and the market for secondary (recycled) materials don't exist.

Sources of Information

Circular economy has its roots in the field of Industrial Ecology (see Box 1) and draws on concepts and principles from this academic field. Ellen MacArthur Foundation has played a key role in promoting Circular Economy and has published several reports which are accessible from the foundation's website (Ellen MacArthur Foundation).

Case studies that apply the circular economy paradigm to existing and emerging products and technologies are growing in the academic literature and may offer valuable reference. Ultimately, information on a product's circularity may require directed communications with the focal firm.

5.2. Certifications

Basis

Certifications offer a way for companies to demonstrate the quality of their service or product with third-party verification (see Box 6). Certification is a voluntary process, but can often provide valuable information about the company and/or the innovation. Some commonly used certifications are listed in Box.4. While certification can be a good indicator, it is not an assurance of sustainability performance. Most certifications focus on a single property or aspect of a product or business, instead of evaluating the whole system.

Research has shown that companies with certifications outperform those without in a number of business metrics. For example, (Treacy et al. 2019) and (Mokhtar and Muda 2012) demonstrate that both environment-related certifications (e.g., ISO 14001) and quality certifications (e.g., ISO 9000) correspond with long-term company performance, including fraction of professional employees, cost efficiency, return on assets, and supply chain efficiency.

Guidance Criteria 13

- **Has the company acquired appropriate certifications to distinguish their service or products?**

Certifications should highlight key distinguishing features of an innovation or the company behind it. It may be necessary to combine multiple certifications in order to demonstrate the advantage or performance level that the innovation or focal firm wishes to achieve.

Here, the relevant question is: does the chosen certification reveal the market advantage that the innovation is filling? For example, a certification of the recycled content of a plastic product is one useful indicator of the environmental performance for closed loop systems. Or, conversely, is the market claim really covered by the certification? For example: claiming "home compostable" whereas the certification relates to industrial composting. Another instance that wariness and interpretation may be warranted is with certifications that are based solely on laboratory test performance, as opposed to "real-world" conditions.

Sources of Information

Request information on certifications - received and in-process, or even anticipated - from focal firms. This information should include specifics of the certification (standards, certifier or registrar, etc.) as well as information submitted or revealed (e.g., laboratory results) as part of the certification process. Additional research may be required on the certification and certifying body. It may also be informative to consider other products or firms that have also received the certification.

Box 6. Making sense of Certifications

Certifications offer a standardized measure of performance in a specific category or aspect. Increasing numbers of certifications concern sustainability issues, both social and environmental in nature. It is important to recognize, however, that as a market-based mechanism for addressing social and environmental challenges, standards can vary considerably. An understanding of the standards applied in a given certification can help in interpreting its meaning for a product or business. Acknowledging the certifying body can also help in assigning credibility and trust in a certification: in general, independent, non-profit or governmental certifying bodies are more likely to maintain unbiased standards than, say, organizations closely associated with industry groups, but this is certainly not an absolute rule, and certifications should be examined individually.

Certifications can also be narrowly defined on a specific aspect or property, and it will be important not to conflate this with broader sustainability claims. Further, some certifications can be based on theoretical performance without demonstration of real-world results. An example of this might be a certification of biodegradability or compostability that is based on material properties without an actual demonstration of performance.

The table below lists a number of popular certifications, organized into topical categories, that may be relevant to plastic waste reduction innovations. This listing is by no means exhaustive, and does not represent a vetting or endorsement of the examples, merely a representation of certifications that may be of interest.

Table 5. Examples of certifications that may be relevant to plastic waste reduction innovations.

Certification Category	Examples	Certifying body	coverage	For more information...
Business strategy	B Corp	B Lab (non profit)	social/environmental performance, transparency, accountability, balancing profit and purpose	https://bcorporation.net/
Energy Savings	Energy Star	US EPA/ DOE	Energy efficiency	https://www.energystar.gov/
Environmental Management	ISO 14000	Numerous registrars based on standards set by ISO	Minimizing negative env. impacts	https://www.iso.org/iso-14001-environmental-management.html
GHG Emission	Product Carbon Footprint Label Science Based Targets Initiative Climate Neutral Certified	Carbon Trust (company) SBTi (non-profit partnership) Climate Neutral (non-profit)	Multiple levels of emission declarations Commitment to emission reduction path Footprinting, offsetting, reductions	https://www.carbontrust.com/what-we-do/assurance-and-certification/product-carbon-footprint-label https://sciencebasedtargets.org/ https://www.climateneutral.org/

Water Savings	WaterSense Certification	US EPA	Water use efficiency	https://www.epa.gov/watersense
Biodegradability	BPI certification	Biodegradable Products Institute	biodegradability/compostable	https://bpiworld.org/
Plastic Recycle	Postconsumer Resin (PCR) Mass Balance Certification Recycled Claim Standard (RCS) Global Recycled Standard (GRS)	Assoc. Of Plastic Recyclers (3rd party certified) American Chemistry Council standards (3rd party certified; e.g., ISCC) Textile Exchange	Post-consumer recycled content Certifying recycled content claims Recycled input & chain of custody	https://plasticsrecycling.org/apr-pcr-certification https://plastics.americanchemistry.com/recycling-and-recovery/Mass-Balance-Certification-Principles-2020.pdf https://textileexchange.org/standards/recycled-claim-standard-global-recycled-standard/
Quality assurance	Recycled plastic Component recognition	UL	Assures recycled plastic is substitute for virgin	https://www.ul.com/services/recycled-plastics-testing-and-certification

5.3. Life Cycle Assessment

Basis

Even if a product innovation reduces overall plastic waste, it may still cause worse overall environmental impacts such as increased greenhouse gas emissions (GHGs). For example, if a reusable packaging model requires additional shipping or needs to be washed for reuse, total amount of plastic waste may decrease but overall GHGs could increase. Therefore it is critical to evaluate the environmental impacts of an innovation from a systematic, holistic perspective.

Guidance Criteria 14

- Has a reputable and robust life cycle assessment (LCA) been conducted in accordance with ISO standards that indicates potential for significant environmental improvement?

Life Cycle Assessment (LCA) is a widely recognized systematic accounting method used to quantify the environmental impacts of the products, processes and services that provide our human needs (see Box 7 for more on LCA). The defining feature of LCA is that it considers the full "life cycle" of a product: from resource acquisition (mining, oil drilling, etc.) through material production, product manufacturing, transportation and distribution, product use, and end-of-life disposal.

ISO standards exist detailing the properties of quality LCAs. Still, the methodology is highly fluid, allowing application to a multitude of system types and inquiries. Methodological choices made as part of a given LCA can influence the results and attention is required to these choices to assure reasonable interpretation. The following guidance criteria identify some key points of inquiry. However, when questions arise about the methods and results of an LCA, consultation with an experienced LCA practitioner may be warranted.

Guidance Criteria 15

- Does a comparative LCA demonstrate performance advantages over the status quo?

5.3.1. Evaluating the Quality of a Life Cycle Assessment

This set of LCA quality guidance criteria are intended to be used to provide a more rigorous and deeper analysis of specific environmental performance claims, acknowledging that there are multiple potential pathways that environmental performance can be verified. The sub-criteria in this section are:

LCA Quality Criteria 1

- **Was the LCA conducted by a reputable consultant or other LCA expert?**

This helps assure that standard procedures and best practices were followed. It does not mean that the report cannot be written by internal staff or partners, but LCA is a nuanced practice and depth of experience, either of an individual or a consulting organization, often translates into more reliable results and, perhaps more importantly, interpretation of those findings.

LCA Quality Criteria 2

- **Was the LCA peer reviewed in accordance with ISO standards?**

This offers additional confidence in methods. The ISO standards (ISO 14044) specify the type of information that should be communicated in a report and state that LCAs intended for public communication of comparative assertions undergo a formal review by a panel of experts.

LCA Quality Criteria 3

Are the functional unit and system boundaries appropriate for product/system and comparisons?

System boundaries dictate what is included and excluded in a given study; it is important to consider whether a study includes the life cycle stages and processes that are intuitively anticipated to have notable environmental impacts and exclusions are justified. Further, when the LCA makes comparisons between different products or systems, it is critical that system boundaries cover equivalent life cycle stages in each. The functional unit is the relative basis of results (the denominator in quantitative values) and can strongly influence our interpretation of the LCA, especially when comparing very different products/services that provide the same "function;" think: reusable steel bottle vs. disposable plastic water bottle. Here, the basis of analysis is not a single bottle but rather the delivery of a certain volume of water; e.g., 1000 liters, which would require 1000 disposal one liter bottles vs potentially one reusable bottle depending on its service life. Further explanation of functional units and system boundaries and their implications is provided in Box 3.

LCA Quality Criteria 4

- **Have sufficient uncertainty and sensitivity assessments been performed to consider an expected range of real-world situations?**

Uncertainty in the input data used in an LCA means uncertainty in the results; an uncertainty assessment demonstrates the extent to which data uncertainty influences the outcome or conclusions of a study. Data uncertainty can be compounding, so the influence of parameters should be considered together.

Sensitivity assessment, on the other hand, considers how a given parameter changes the results of the study. A study is typically conducted around a specified set of conditions - for example, transportation distances, recycling rates, number of reuses - but variation in these are likely. A good sensitivity assessment will offer information about which parameters most strongly influence environmental performance and therefore which parameters require the most attention in business development and implementation.

For example, a reusable packaging system may show favorable life cycle results in comparison to a single-use alternative for GHGs. A sensitivity assessment will indicate when the reusable system will be less favorable as transportation distances increase, such as for return trips for pooled washing.

LCA Quality Criteria 5

- **Has data quality been taken into consideration in interpreting results?**

Availability of high-quality data is often a limitation in LCA. Typically, this data quality is evaluated as part of a study, recognizing where data quality was perhaps less than ideal and accounting for this added uncertainty when interpreting results. This may take the form of uncertainty assessments (see below) or added precaution in drawing firm conclusions.

Box 7. Life Cycle Assessment

Life cycle assessment (LCA) refers to the process of compiling and evaluating the inputs, outputs and potential environmental impacts of a product system throughout its life cycle (ISO 2006a). In other words, it is a systematic accounting method based on a standardized framework and terminology that is used to quantify the effects on the environment from the systems and stuff that meet our human needs. The focus in LCA is on a given product, process or service, and may consider a number of different environmental impact indicators.

LCA is complex: it often requires modelling of complicated systems and biophysical processes. It demands large amounts of data, often data that simply are not available. While LCA can potentially encompass multiple environmental factors, often resource and data availability dictate a focus on a few key indicators such as greenhouse gas emissions or water use. Assumptions are required to overcome limitations in data and other uncertainties. The LCA method is intentionally flexible to accommodate a wide range of applications, scopes and inquiries. Sometimes assessments are conducted at more of a "scan level", as not all questions require a completely thorough accounting of every detail. Because of all of these limitations, the depth, breadth and quality of studies called "life cycle assessment" vary widely. A good LCA is a difficult and wonderful thing; but it is important to recognize that not all LCAs are created equally.

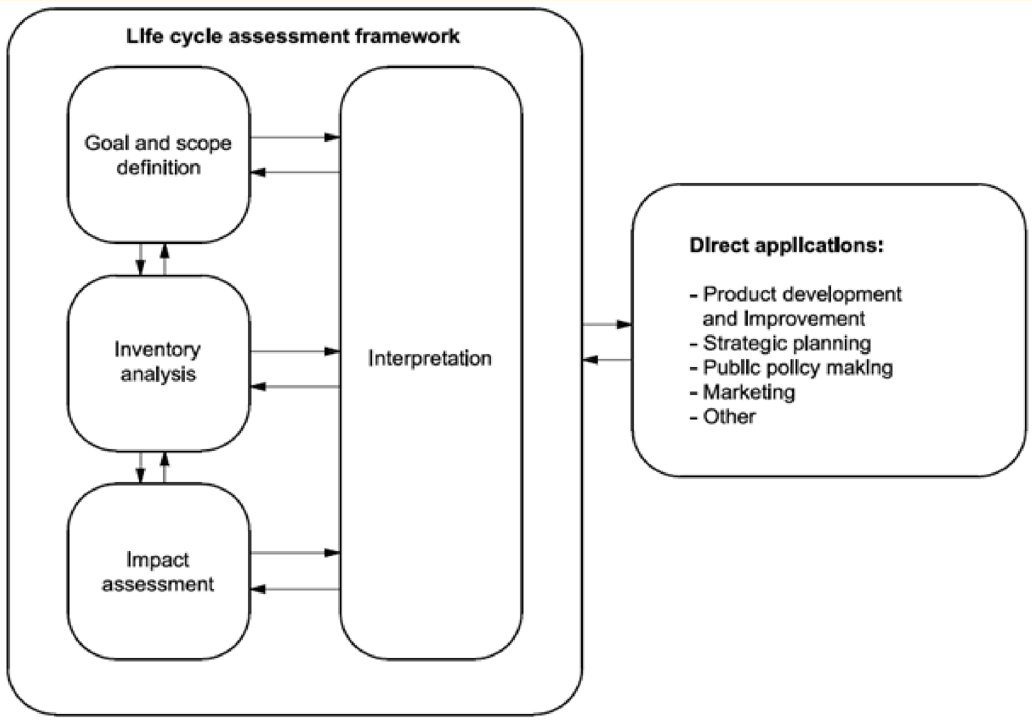

Figure 9. The general LCA framework, as presented in (ISO 2006a).

The general methodological framework for LCA is commonly illustrated as in the figure above. Typically, the workflow is from top to bottom, with interpretation occurring throughout. However, the back-and-forth arrows demonstrate the iterative nature of LCA: often information about a system is gained in a later phase that requires the practitioner to revisit and reconsider choices made previously. Numerous texts, including the ISO standards themselves, detail the approach and stages of LCA ((ISO 2006a; ISO 2006b; Curran 2012)). Here we offer only a brief orientation.

Despite standardization, LCA remains a rather fluid methodology, capable of examining a wide variety of system types. This also means, however, that fully understanding and interpreting the results of an LCA requires an appreciation of the specific methodological choices employed. Much of the LCA procedure is defined and influenced by the specific question to be examined and the context around answering that question. It is in the ***goal and scope definition*** phase where that question is defined as clearly and explicitly as possible, along with the intended application, the reasons for conducting the study, and the intended audience. Central to this phase is defining the function of the system, as this becomes the basis for comparisons and reporting. LCA is a relative accounting method, such that results are given relative to a quantified definition of the system function, called the functional unit. For example, comparing a natural gas fired electricity generation plant directly with a solar panel makes very little sense. However, a well-defined function, say "supplying a MW of electricity over one month," allows a meaningful comparison of otherwise disparate systems. The functional unit also permits meaningful comparisons between different stages of the life cycle: for example, LCA could describe how environmental emissions associated with the manufacturing of an electricity power plant compare with those from operation.

Inventory analysis, the second phase of LCA, involves "the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 2006a). Inventory analysis is often very data and calculation intensive. In the standard LCA approach, known as process-based LCA, the life cycle under study is divided into unit processes. These include things like coal mining, steel production, assembling and producing an LED lightbulb, operating an electric teakettle, transporting by semi-truck, or recycling waste PET plastic. In LCA, a unit process is typically treated as a black box that converts a collection of inputs into a collection of outputs. Inputs include products (from other processes), natural resources (minerals and ores, energy carriers, biotic resources, land), or waste to be treated. Outputs also include products, waste for treatment, and residuals to the environment such as air, water and soil pollutants, and waste heat. Inventory analysis involves quantifying the inputs and outputs of interest across each unit process and the interconnections between each that form the product's life cycle. Digital databases and dedicated LCA software can greatly aid in harmonizing this complex and exhaustive accounting. Life cycles in theory can be infinitely large: there is almost always an additional upstream input that also requires materials and resources. This is addressed in process-based LCA by assigning a cut-off criteria, a point where additional contributions are negligible to the results of the study. Another perennial challenge encountered in the inventory analysis phase occurs when a process that cannot be further divided produces several co-products. Take, for example, the production of soy oil. Soy oil cannot be produced without also producing soymeal, which also has economic value. The upstream impacts leading to oil refining, including the agricultural production of soybeans, must somehow be allocated to the co-products. There are a number of approaches to doing this, and ISO standards offer a suggested prioritization of those approaches, but rarely is there a "right" answer and it becomes a methodological choice within the study. Debates on the relative merits of these approaches can be left to LCA practitioners and experts, but all who interact with LCA should appreciate that such choices can influence the results of an LCA.

The outcome of an inventory analysis can be dozens, hundreds, or even thousands of resource and emissions flows. What do these mean? What are the impacts on the environment? This is the purpose of the ***impact assessment*** phase. Environmental impacts are divided into categories, such as climate change, eutrophication, toxicity, water use impacts, and fossil energy depletion. The impact categories of interest and relevance to a particular study are defined in the Goal and Scope phase. Environmental impacts typically involve a cascading series of causal mechanisms. For example, an emission of greenhouse gases leads to changes in the composition of the atmosphere, which leads to a change in the radiation balance, which contributes to a change in the temperature distribution, which leads to changes in climate, which can affect ecosystems and human activities, etc. Scientists in chemistry, meteorology, ecology, and beyond have developed models to represent such causal relationships, but in general, the further along the causal chain, the more uncertain and contentious these predictive models become. Choosing to characterize an environmental impact earlier in the causal chain as a midpoint impact indicator, such as global warming potential reported in carbon dioxide equivalents, introduces less uncertainty. In some applications, however, the communicative benefit of a more intuitive endpoint impact indicator, such as loss of human life years, may outweigh the added uncertainty. In addition, the causal chains of various environmental impacts typically converge on a few "areas of protection" at the endpoint, allowing more direct comparisons (albeit with greater uncertainty) and aggregations of disparate indicators.

A variety of impact assessment methods have been developed for use in LCA, and these are typically implemented in LCA software, making their application fairly straightforward. Interpretation of impact assessment results, however, can be challenging and often requires an understanding of and experience with the methods employed. Further, there is little specification or guidance in choosing impact assessment methods, and differing methods can and do offer different results for the same impact category. Again, discussion of the relative merits of various assessment methods is beyond the scope of this text, but it is important to recognize that such choices can matter. Thoroughly conducted LCAs will demonstrate and discuss variability introduced by assessment method choice.

The ***Interpretation*** phase involves evaluating the findings of inventory analysis or impact assessment (or both) in relation to the defined goal and scope in order to reach conclusions and recommendations. It generally involves an acknowledgement of limitations and assumptions, assessments of data quality and completeness, as well as sensitivity analysis aimed at characterizing the reliability and robustness of conclusions. This occasionally requires returning to decisions, analysis or data collection addressed earlier in the LCA in order to refine and improve the study. Conclusions are drawn and recommendations made by putting results in the context of decision-making and limitations.

Strengths

LCA was initially developed to evaluate and improve products, particularly in product development, and the method excels in this role of identifying unexpected opportunities to reduce impacts, or unexpected consequences of a particular design choice. A classic example of this is Procter & Gamble's LCA of household laundry detergents in the early 2000s. After determining that the overwhelmingly dominant impacts associated with laundry detergents arise not from resource extraction or packaging manufacture, but from the energy required to heat water in the use phase, P&G developed a new detergent that could clean just as effectively in cold water (Saouter and Van Hoof 2002).

As implied earlier, LCA can also be a valuable way of comparing different systems or products that offer the same service or function, but involve dramatically different processes. Classic examples include comparisons of glass and plastic beverage containers or paper and plastic shopping bags.

The strengths of LCA include: Evaluating the environmental consequences associated with a given product or process.

- Highlighting "hot spots" in a product or process life cycle that warrant focused attention. Where are the largest burdens?
- Analyzing the environmental trade-offs associated with one or more products or processes. Trade-offs can occur between stages of a product life cycle, between environmental impact categories, between societies/geographic regions, or between generations.
- Identifying unexpected consequences of a product or innovation.
- Identifying "burden shifts" between environmental impact categories or across life cycle stages. In other words, does addressing an environmental problem at one stage simply move the impact somewhere else?
- Comparing the potential impacts between two or more products or processes.

LCA has found application in:

- product development and improvement
- strategic planning
- marketing

Weaknesses

LCA is a powerful tool. But it can't do everything. Understanding the limitations of LCA is critical to identifying proper applications. LCA offers a relative look at potential environmental impact that can help inform decisions, but must be balanced with other considerations and cannot answer absolutely whether a product is sustainable or not. It can be data intensive and costly, and only proxy data may be available.

- Process-based LCA is typically data intensive, which often means that it is time-consuming and costly. It can offer extremely valuable insights that, when implemented, in many cases translate into direct environmental and financial savings and as such, LCA can be a very sound investment. Still, these intensities can make it inaccessible for some stakeholders and applications. That said, there often is value in simplified approximations – "back-of-the-envelope" or scan-level LCAs based on a limited scope and data – but interpretation must carefully account for these limitations.
- LCA can help inform decision-making. Ultimately, however, it must be taken into account with a suite of other considerations including costs and social implications. LCA can help identify an opportunity, but additional tools and protocols are likely needed to help inform and support action.
- LCA offers an indication of potential environmental impact. It is not a measure of impact that has occurred in the absolute sense. This is perhaps only a weakness if it is misinterpreted.
- LCA is a relative assessment method. As a consequence, and perhaps contrary to popular belief, LCA cannot tell if a product is "sustainable" or "environmentally friendly." LCA can only indicate if product X is "more sustainable" or "more environmentally friendly" than product Y, or that the use phase is the "least sustainable" or "least environmentally friendly" part of the life cycle for product Z.
- There are challenges when combining LCA results across impact categories. Aggregating results into a single score requires a valuation method that can include subjective weighting on separate impact categories (i.e. water use and GHGs).
- Most LCA datasets are based on industry averages, or sometimes even specific examples. As such, they often do not represent the specifics of a particular product chain or fully capture the variability inherent across industries and economies.
- The analytical structure of LCA assumes linear scaling of technologies. This assumption means, for example, that producing 1 kg of steel has the same impact per kg as producing 5 million kg of steel. In some applications, consequential LCA is an attempt to address this limitation.

Guidance Criteria 16

- **Has the academic literature pertaining to products/services that are similar or related to the innovation been reviewed? What has this review revealed as critical parameters for determining environmental performance or issues of concern?**

Often reviewing previous research studies such as life cycle assessments of related products or product categories can offer important guidance to both the environmental concerns and system parameters that will be important for new innovations.

5.4. Other: health and safety, regulations, future trends

5.4.1. Health and Safety

Guidance Criteria 17

- Has the health, safety, and rights of all potentially impacted individuals been considered and respected?

The environmental and human health impacts of the plastics industry disproportionately impact marginalized communities, from raw material extraction, manufacturing, and disposal. Plastic waste pollution in marine communities impacts the livelihoods of communities that depend on marine ecosystems and globally, many marine communities do not have the appropriate infrastructure to manage plastic waste.

One of Ellen MacArthur principles, but important to call out more specifically, given environmental justice issues associated with plastic production and waste.

5.4.2. Regulations

Guidance Criteria 18

- **Are there anticipated potential regulatory risks or avoided risks of the business model or product in question?**

Existing and anticipated regulation and legislation on plastic should be considered in evaluating the risks or avoided risks associated with a business model or product. Each will influence actors in the plastics value chain differently and should be interpreted from the perspective of how it will impact the focal firm. For example, no policies or regulations currently exist that directly impact raw material producers, however they will be indirectly impacted by policies such as increased requirements for recycled plastics.

Historically, plastic packaging has been the focus of most policies and regulations. Some regulations to consider are single-use bans, minimum requirements for recycled content, bans of specific types of plastic that are particularly difficult to recycle, or changes to disposal and end of life outcomes (i.e., China's ban on imported plastics). Other policy considerations include Extended Producer Responsibility (EPR) and deposit return schemes. EPR requires manufacturers to address the possible negative externalities of the products they produce and greatly increases their financial and/or physical responsibility. For example, EPR may require manufacturers to take back products at the end of life for proper recycling or disposal (OECD). Deposit return schemes in which a customer pays an upfront deposit and is refunded upon return are growing in number around the world. Deposit return schemes should be considered most specifically for beverage and food packaging companies (James).

A focal firm may be actively avoiding a regulatory risk, such as in the case that a single use plastic ban can be advantageous for companies with a reuse business model (James). Policies and regulations are often place-based at the state or national level and should be considered in evaluating the potential to scale.

5.4.3. Future Trends

Guidance Criteria 19

Are there future trends (e.g. shifts in renewable energy consumption, changing regulatory environment) that would significantly impact the environmental profile or overall sustainability of the innovation?

6. Evaluation Summary and Investment Decision

We recommend that the results from the use of PRISET be organized in an overall evaluation matrix to facilitate investment decision making.

A simple structure listing each of the Guidance Criteria and Technology/Innovation Specific Screening Criteria along with key Performance Metrics: Scale of Plastic Waste Reduction (i.e., potential tons of reduced), LCA (e.g., life cycle greenhouse gas emission reduction) and Certifications (list specific verified environmental attributes).

		Criteria	Rating
Firm Level Sustainability	Mission & Vision	GC 1	
		Mission Overall	
	ESG	GC 2	
		GC 3	
		GC 4	
		GC 5	
		ESG Overall	
Firm Level Sustainability Overall			
Innovation Technology Level Characterization & Readiness	Innovation/Technology Classification & Screening	SC 1	
		SC 2	
		SC ...	
		SC ...	
	Innovation/Tech. Classification & Screening Overall		
	Scale of Impact	GC 6	
		GC 7*	
		Scale of Impact Overall	
	Market Readiness	GC 8**	
		GC 9	
		GC 10	
		Market Readiness Overall	
Innovation Technology Level Characterization & Readiness Overall			
Systems Level Assessment	Circular Economy	GC 11	
		GC 12	
		Circular Economy Overall	
	Certifications	GC 13	
		Certifications Overall	
	LCA Quality	LCA QC 1	
		LCA QC 2	
		LCA QC 3	
		LCA QC 4	
		LCA QC 5	
		LCA Overall Quality	
	LCA	GC 14	
		GC 15	
		GC 15	
		***LCA Overall	
	Health and safety, regulations, future trends	GC 17	
		GC 18	
		GC 19	
	Health and Safety, Regulations, Future Trends Overall		
Systems Level Assessment Overall			
Investment Decision			

* Associated Metric: Waste Reduction
** Associated Metric: TRL Level
*** Associated Metric: LCA Results

Figure 10. PRISET Evaluation Matrix.

The overall objective of PRISET is to assist practitioners to systematically assess innovations intended to improve the environmental impacts associated with plastic production, use, and disposal. The guidance criteria are intended to assess potential environmental improvements that may result from investment in a new innovation, as well as to identify areas of concern and determine where additional research may be needed. Therefore**, a negative evaluation on one or more of the guidance criterion should not necessarily be seen as disqualifying**. Instead, the tool is intended to assist in a holistic evaluation to better understand the benefits as well as potential areas of caution that may need to be addressed or further explored.

PRISET recognizes differences in the technology readiness level of plastic waste innovations. Different levels of technical maturity should be taken into account when applying the guidance criteria. One of the challenges for **early-stage** companies or innovations is that the technology may be less defined, and lack of data and uncertainty regarding deployment in market conditions will limit appropriate assessment methods. For **mature companies** whose technology is commercialized, **certifications, life cycle assessments**, or other quantitative analyses can offer more detailed assessment of environmental impacts as well as performance relative to incumbent or competing technologies/products/services. Detailed life cycle assessments and full certification may not be realistic for early-stage innovations, whereas there may be a higher standard that is applied to more developed technology. Further considerations that are specific to these technology categories are addressed using guidance criteria and metrics specific to the technology deployed, the market affected, and often the behaviors impacted.

PRISET is not an expert system that scores environmental sustainability performance of innovations. Judgement is ultimately required to incorporate guidance on environmental performance with other critical metrics used to evaluate potential investments. PRISET offers foundational background information and supportive direction for entrepreneurs, investors, consultants and other vested parties through what otherwise might be foreign and intimidating assessments. In addition, to serving an evaluation function **the tool can provide innovation companies a platform to improve their sustainability performance**.

7. Case Study: ClubZero (Formerly CupClub)+

Case Overview

ClubZero is a company partnering with businesses and retailers to service retail cafes, in-house cafes, canteens, restaurants, coffee or tea points. They offer reusable cups to customers who can return the cups at multiple drop-off points. The cup is tracked by RFID systems. The company incentivizes the user to return the cups within a set time span. If this does not occur, a late fee is charged. Figure 11 shows some images from their early marketing.

ClubZero's financial status is currently in accelerator / incubator backed status. It has raised £450k from the pre-seed round on Feb 12, 2018, and £360k from the second pre-seed round on Feb 13, 2019.

ClubZero is a winner of the Circular Design Challenge award at New Plastics Economy led by the Ellen MacArthur Foundation. ClubZero is currently piloting their service in selected cafe retail stores in London and Palo Alto, CA. Additionally, ClubZero is one of the limited numbers of focal firms that provided a comprehensive Life Cycle Assessment (LCA) report to review. With the LCA, we were able to evaluate the environmental benefits and understand how effective their model is consistent with the criteria in this tool.

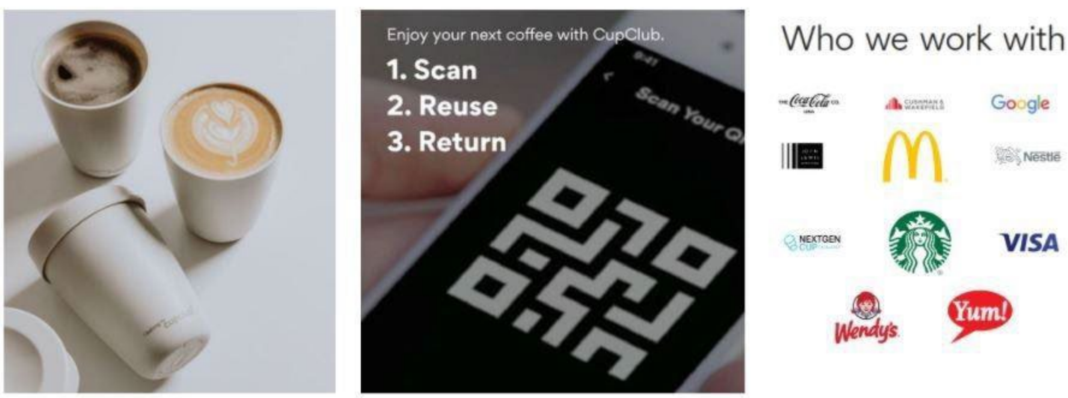

Figure 11. Early marketing of ClubZero.

After going through the public information on ClubZero's official website and their LCA report, we gathered the following **basic information**:

- The 2018 Sustainability Report outlines a relatively comparative analysis of the environmental impacts of ClubZero against alternative single use coffee cups and a reusable ceramic cup.
- The main benefit of ClubZero is reducing plastic waste through single use cups, which are commonly made of Polyethylene terephthalate (PET), Polystyrene (PS), and Polypropylene (PP). The report shows that ClubZero also has other benefits such as consuming less water and producing lower greenhouse gases as well as toxic gas emissions than comparable products (e.g., PLA recycled / compostable cup, EPS cup, ceramic cup, etc.).
- ClubZero's cup uses an RFID system to track the individual cup use, which can give service companies useful data such as the consumption pattern of the customers. The typical cup consists of 49.3g of PP and the lid from 22.03g of LDPE.
- The software app. for ClubZero is active and running. ClubZero cups are free for customers but

+ At the time of this case study was conducted, ClubZero operated under the name CupClub.

charge businesses at $0.25/drink sold for offering their cups as a service. It is still unclear if businesses will be incentivized to utilize this service since costs are coming from their bottom line.

Evaluation with PRISET

Part A Firm Level Sustainability Strategy, Goals, and Governance

Mission and Vision

GC1 Does the mission and vision convey a purpose that contributes to advancing sustainability?

There is no clear mission and vision statement on ClubZero's website, but the following words could serve as their goals:

- "ClubZero partners with businesses to make drinks-on-the-go more sustainable; working together towards the ultimate goal of zero waste."
- "Each step of the ClubZero journey is eco-friendly: from manufacturing, to cleaning, to transport using 50% less CO2 than single-use cups."

The company claims that its product is reusable and could make use of its drinks-on-the-go models to achieve zero waste in the end. Certainly, when making further analysis, evaluators need to accompany measurements in the potential scale section to fully understand the exact number of plastic waste reduction. The company indicates that each step of the process is eco-friendly, from manufacturing, cleaning, to transporting. Evaluators need to analyze the data in the LCA section to fully understand the life cycle sustainability compared to traditional or typical single-use plastic cups.

Environmental, Social, and Governance (ESG)

Standardized reporting

GC 2 Does the company report to major standardized ESG platforms such as Global Reporting Institute (GRI), Sustainability Accounting Standards Board (SASB), or the Task Force on Climate-Related Financial Disclosures (TCFD)?

It does not appear that ClubZero reports to any major standardized ESG Platforms. This is likely due to their small size.

Strategy and Goals

GC 3 Does the company discuss and detail their climate strategy? Are specific, measurable goals articulated in this plan?

As of 2021, they only have issued 1 sustainability report in 2018 which is focused on the LCA of their product. It does not appear that ClubZero has a detailed climate strategy or it is not readily accessible. This is likely due to their small size.

GC 4 Does the company outline a specific sourcing strategy that aligns with their environmental strategy?

It does not appear that ClubZero has a detailed sourcing strategy, and it is unclear where the cups are manufactured and washed. This information is potentially missing due to their small size, or they may still be deciding who their long-term suppliers may be.

Partnerships

GC 5 Does the company have and maintain key partnerships? Is the company involved in commitments and initiatives that demonstrate commitment to environmental strategy?

ClubZero won Ellen MacArthur Foundation's New Plastics Economy Prize in 2017. As a result, they participated in a year-long accelerator program supported by the US innovation hub, Think Beyond Plastic. This is an impressive prize and shows the strength and acceptance of ClubZero as a sustainable solution to ending plastic waste in the reuse market at large. Winning this prize demonstrates EMC's stamp of approval. They are also backed by R/GA, atomic, and Seedcamp. Although these organizations are not specific to plastic waste mitigation, they are still notable and provide credibility.

There is also mention of partnerships with Closed Loop Fund and IDEO on their website, well established circular economy and design firms. However, they do not detail the nature of their partnership and only mention it as part of their pilot lunch with Starbucks and McDonalds in Palo Alto, CA.

ClubZero has established relationships and partnerships with global retailers such as McDonalds, Starbucks, Coca-Cola, and Nestle which also provides credibility and insight into where and how they plan to scale and general market interest.

Firm Level Sustainability Strategy, Goals, and Governance Assessment Summary

Overall assessment for this section is that ClubZero in line with what might be expected of a small relatively new company, focused on a single product. The organization has effectively established relationships and partnerships and won several awards that are specific to plastic waste reduction solutions. Some of the mission/vision, sustainability accounting, and reporting are under-developed or not publicly available. This is not unusual for a company of this size.

Part B Innovation/Technology Level Characterization and Market Readiness

Technology/Innovation Classification and Initial Screening

Reuse and Refill:
The service provided by ClubZero is a typical reuse & refill innovation, and the collection process is improved by using an RFID system to track each cup. For this innovation, we need to consider both questions for reuse & refill innovations and the related tracking system.

SC 1 Will collection, return transportation, and cleaning of reusable packages increase the use of fossil energy or strain a water scarce region compared to the incumbent system (e.g., single use system)?

By comparing the equivalent consumption of different cups, the LCA establishes several break-even points for each kind of cup. According to their data, the cup can be used at least 132 times, which is higher than break-even points of all disposable cups considered in this LCA study. Therefore, the life cycle of a ClubZero product is expected to have lower energy and water use than disposable cups over its lifetime (see breakeven points below in figure 13).

SC 2 Does the new material (plastic or non-plastic) used for the reuse scheme have a robust recycle market or viable compost solution?

The cup is made of LDPE and PP, which are commonly accepted by most recyclers as the source of post-consumer resin, and both have robust recycle markets.

SC 3 What is the break-even number of reuses where total energy use and GHG emissions are reduced versus the single use incumbent?

As shown in Figure 13, the breakeven number of reusing is 72 vs. paper/PS cups at 1% recycle rate and 132 at 80% recycle rate; 100 vs. EPS cup; and is better than ceramic until about 2000 uses.

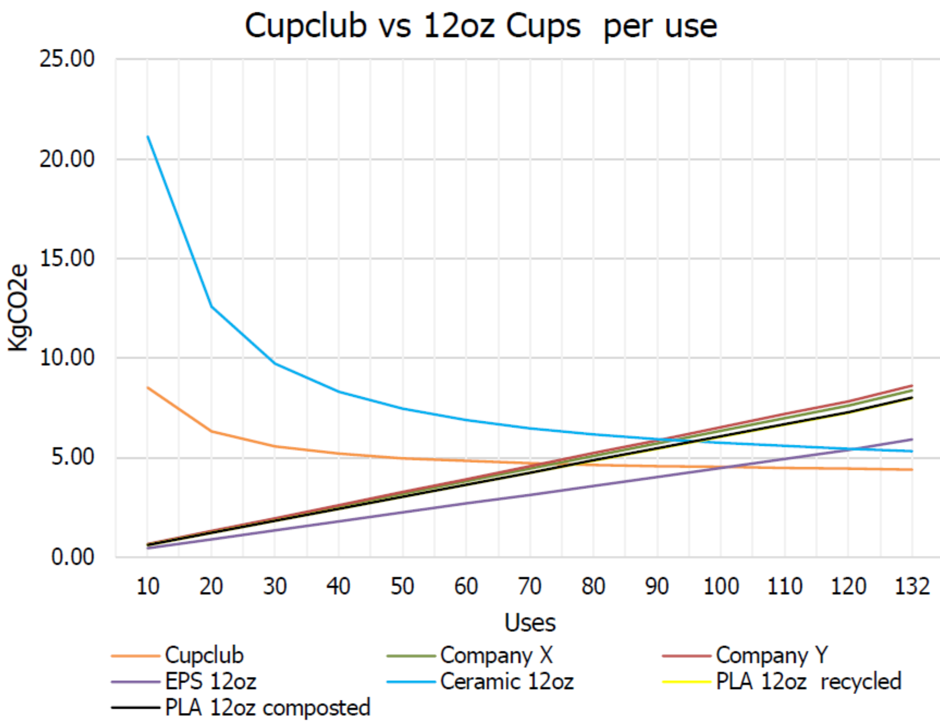

Figure 12. Emission comparison of ClubZero and other 12oz cups (Dowling 2018).

SC 4 How will performance of the reuse scheme change when renewable energy is widespread and commonplace?

Environmental impact of the reuse scheme will decrease specifically in washing and transportation as renewable energy becomes more widespread.

Scale of waste reduction

GC 6 Does the intervention target a product with a high likelihood of losses to natural environments, a difficult to recycle plastic or product, or other high priority waste stream?

The company's cup consists of PP and LDPE, but the comparable alternatives are paper cups with PE/PLA, EPS, and ceramic. Ultimately, this is a plastic solution that will displace a number of single-use products, with the displacement of plastic lids on paper cups likely the most prevalent (see table below for more detail). The targeted displacement is a common and ubiquitous plastic. Coffee cup lids may be a waste stream that could experience lower rates of recycling relative to other plastic products.

GC 7 What is the maximum potential for this intervention to reduce plastic use/waste?

These numbers may be compared to the ClubZero specifications of 49.3g of polypropylene and the lid from 22.03g of low-density polyethylene. It appears over the lifetime of 132 uses, ClubZero reduces plastic waste when compared to these cup alternatives.

It is important to note that as the recycling rate of paper cups goes up, the attractiveness of ClubZero goes down. For example, according to the LCA data, paper cups become favorable over ClubZero in total emissions once the recycling rate of paper cups reaches 80%. However, it is well known the recyclability of these kinds of cups is difficult as they are blended materials (paper and plastic liner).

Besides comparing the performance of ClubZero with other competitors, we need to consider the extent to which a given innovation will scale within the broader economy to fully investigate the sustainability of ClubZero's service.

ClubZero has provided the material information of their reusable cups and compared them with their competitors (Table 6). It is estimated that 50 billion disposable coffee cups are consumed in the US every year, and if all disposable cups are replaced with ClubZero's product, 0.183 Mt of plastic can be reduced per year which accounts for around 0.3% of total US plastic consumption.

Table 6. Material comparison between ClubZero and disposable coffee cup

Cupclub Cup		Single use coffe cup		Equivalent coffe cups (132 use)	
PP (g)	49.3	Paper (g)	10	Paper (g)	1830
LDPE(g)	22	PE (g)	1	PE (g)	554.4
Reuse time(s)	132	Corr.sleeve (g)	3.7	Corr.sleeve (g)	488.4
		PS-lid(g)	3.2	PS-lid(g)	422.4

Scale of Potential Impact Assessment Summary

Overall assessment for this section is that ClubZero has the potential to displace a very common plastic waste stream in the form of coffee cup lids, which may experience lower than average recycling rates. The overall potential market is displacement of 0.3% of total US plastic consumption and 50 billion units. Given the large number of units of existing disposable cups, the visible impact of ClubZero may be quite large, even though the total mass of displaced plastic may be relatively low.

Technology and market readiness

GC 8 Is the technical quality of the innovation sufficiently competitive?

The ClubZero product provides similar or superior technical performance to disposable coffee cup alternatives. It is not clear how overall product performance may change or degrade over 130 uses. The cups are installed with RFID chips to track them. It is not clear if the RFID chip will degrade over the lifetime of the product.

GC 9 Does the required physical and/or logistical infrastructure exist to support adoption of the innovation? What infrastructure changes may be required

ClubZero requires installed physical infrastructure of cup collection points at locations that are convenient for consumer drop-off. The innovation also requires collection, transportation, and cleaning infrastructure in order to reclaim and reuse the cups.

GC 10 Are there social or behavioral changes required for the innovation to be effective? What efforts will be made to support this change?

ClubZero requires behavioral change from consumers in order to be effective. In order for sustainability benefits to be realized, consumers must return the cups for reuse a sufficient number of times. Currently, incentive/penalty structures are being used to encourage consumers to return their cups at collection points in a timely manner.

Technical & Market Readiness Assessment Summary

Overall assessment for this section is that the Technical & Market Viability of ClubZero will rely on both an effective physical collection infrastructure as well as sufficient consumer participation to return the cups at a rate that supports the required number of reuse cycles needed to realize sustainability benefits.

Part C Systems-Level Sustainability Assessment

Circular Economy Principles (2 criteria)

GC 11 Does the innovation build upon Circular Economy Principles?

According to the sustainability report, the cup is a recyclable (assumed 90% recyclable) petroleum product with RFID chips. Table 7 is a checklist of their list of the CE purpose, which is indicated as an example in our **Circular Economy Approaches** section. The "Pass" code means that the company's innovation passes the characteristic, and the "Verify" code means that this purpose should be investigated further and determined if it is applicable for the ClubZero.

Table 7. Checklist of the circular economy purposes for plastic packaging.

Elimination of unnecessary plastic packaging through redesign, innovation, and new delivery models is a priority	Pass
Reuse models are applied where relevant, reducing the need for single-use packaging	Pass
All plastic packaging is 100% reusable, recyclable, or compostable	Verify
All plastic packaging is reused, recycled, or composted in practice	Pass

The use of plastics is fully decoupled from the consumption of finite resources	Verify
All plastic packaging is free of hazardous chemicals, and the health, safety, and rights of all people involved are respected	Pass

GC 12 How are materials used for the innovation managed at end-of-life?
Further investigation is required to determine that recycling (90% of material claimed to be recycled) of the cups at end of life occurs.

Certifications

GC 13 Has the company acquired appropriate certifications to distinguish their service or products?

ClubZero has not given any information about their certifications, but it doesn't mean that they are not qualified as a sustainable product because the product is still in development and practice. According to their sustainability report, it will be helpful if they can get following types of certifications:

- Business strategy - B Corp
- Energy Savings - Energy Star
- Environmental Management - ISO14000
- GHG Emission - Product Carbon Footprint Label, Science Based Targets Initiative, and Climate Neutral Certified
- Water Savings - WaterSense Certification
- Plastic Recycle - Post Consumer Resin (PCR), Mass Balance Certification, Recycled Claim Standard (RCS), and Global Recycled Standard (GRS)
- Quality assurance - Recycled plastic Component recognition

Life Cycle Assessment with supplemental criteria for evaluating the quality of the LCA

GC 14 Has a reputable and robust life cycle assessment (LCA) been conducted in accordance with ISO standards that indicates potential for significant environmental improvement?

Yes, ClubZero has provided a LCA report which includes comparative analysis of the environmental impacts of ClubZero against alternative disposable single use coffee cups and a reusable ceramic cup. See sub-criteria guidance for “Assessing the Quality of Life Cycle Assessment”, below.

GC 15 Does a comparative LCA demonstrate performance advantages over the status quo?

The company claims its product could have 50% less carbon dioxide emissions, which is quite a strong and measurable indicator in the mission statement. According to Table 3 in this criterion, the company uses life cycle assessment to demonstrate their defined and measurable sustainability goal

Evaluating the Quality of a Life Cycle Assessment

LCA QC 1 Was the LCA conducted by a reputable consultant or other LCA expert?

Study conducted by Giraffe Innovation Ltd, which is one of the UK’s top green businesses due to its extensive experience in delivery of a wide range of sustainability driven projects.

LCA QC 2 Was the LCA peer reviewed in accordance with ISO standards?

A 3rd party peer review was conducted during July, 2018, which follows "[p]rocess intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment" ((ISO 2006b), section 3.45).

LCA QC 3 Are the functional unit and system boundaries appropriate for product/system and comparisons?

System boundaries are clearly defined and appropriate (Figure 12), which follows "consecutive and interlinked stages […] from raw material acquisition or generation from natural resources to final disposal" ((ISO 2006b), section 3.1).

Functional units is sufficient, though somehow arbitrarily defined as 132 uses (expected useful life of ClubZero cup), which follows "Quantified performance of a product system for use as a reference unit" ((ISO 2006b), section 3.20)

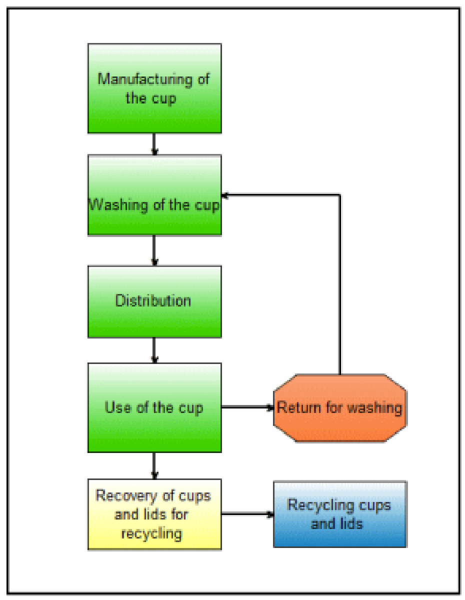

Figure 13. System Boundary of ClubZero's LCA (Dowling 2018).

LCA QC 4 Have sufficient uncertainty and sensitivity assessments been performed to consider an expected range of real-world situations?

Uncertainty in the input data used in an LCA means uncertainty in the results; an uncertainty assessment demonstrates the extent to which data uncertainty influences the outcome or conclusions of a study. Data uncertainty can be compounding, so the influence of parameters should be considered together.

Sensitivity assessment, on the other hand, considers how a given parameter changes the results of the study. A study is typically conducted around a specified set of conditions - for example, transportation distances, recycling rates, number of reuses - but variation in these are likely. A good sensitivity assessment will offer information about which parameters most strongly influence environmental performance and therefore which parameters require the most attention in business development and implementation.

For example, a reusable packaging system may show favorable life cycle results in comparison to a single-use alternative for GHGs. A sensitivity assessment will indicate when the reusable system will be less favorable as transportation distances increase, such as for return trips for pooled washing.

LCA QC 5 Has data quality been taken into consideration in interpreting results?

To check data quality, the data quality indicators have been clearly defined in the report based on ISO 14044 Section 4.2.3.6.2. Each information is measured by these matrices and deemed sufficient. Although most data have been measured by the indicators, the conclusion and interpretation of the LCA report does not directly reflect how the data quality measurements affect the final results.

GC 16 Has the academic literature pertaining to products/services that are similar or related to the innovation been reviewed? What has this review revealed as critical parameters for determining environmental performance or issues of concern?

ClubZero has not offered a review of literature.

Other Health and Safety, Regulations, Future Trends

GC 17 Has the health, safety, and rights of all potentially impacted individuals been considered and respected?

No publicly available data is available regarding community engagement or potential environmental justice issues.

GC 18 Are there anticipated potential regulatory risks or avoided risks of the business model or product in question?

Since ClubZero is a replacement for a single-use option, this business model avoids risks associated with regulation or bans on single-use cups specifically. Areas where there is a tax on single use cups or a deposit return scheme infrastructure in place for reusable items will be advantageous for ClubZero, often called the latte levy. For example, Berkeley, CA placed a $0.25 tax on disposable cups which would offer ClubZero an advantage in the marketplace based on cost.

GC 19 Are there future trends (e.g. shifts in renewable energy consumption, changing regulatory environment) that would significantly impact the environmental profile or overall sustainability of the innovation?

The changing regulatory environment surrounding single-use plastics is most likely to impact the viability of this product. In particular, single-use plastic bans may make adoption of ClubZero more attractive to retailers. Further, greening of the grid would make ClubZero an even more attractive option.

Systems Level Sustainability Assessment Summary

Overall assessment for this section is that ClubZero has the potential to improve the circular economy of the coffee cup industry and reduce environmental impacts and plastic waste. Nevertheless, many of the sustainability assumptions are contingent upon consumer buy-in and whether the reuse rates assumed in the life cycle assessment reflect realistic collection conditions

PRISET Evaluation: <u>ClubZero</u>		Criteria	Rating: Red	Rating: Yellow	Rating: Green	Comments
Firm Level Sustainability	Mission & Vision	GC 1		■		There is no clear mission and vision statement on ClubZero's website, but the following words could serve as their goals: "ClubZero partners with businesses to make drinks-on-the-go more sustainable; working together towards the ultimate goal of zero waste." and/or "each step of the ClubZero journey is eco-friendly: from manufacturing, to cleaning, to transport using 50% less CO2 than single-use cups." The company claims that its product is reusable and could make use of its drinks-on-the-go models to achieve zero waste in the end. Certainly, when making further analysis, evaluators need to accompany measurements in the potential scale section to fully understand the exact number of plastic waste reduction. The company indicates that each step of the process is eco-friendly, from manufacturing, cleaning, to transporting. Evaluators need to analyze the data in the LCA section to fully understand the life cycle sustainability compared to traditional or typical single-use plastic cups.
	Mission Overall			■		ClubZero's lack of a clear mission and vision statement along with an unvalidated assertion that the company reduces waste in the on-the-go drink market was a weakness noted at the time of our assessment. The company does provide some promising goals, but will need to put more robust systems of accountability in place.
	ESG	GC 2	■			It does not appear that ClubZero reports to any major standardized ESG Platforms. This is likely due to their small size.
		GC 3		■		As of 2021, they only have issued 1 sustainability report in 2018 which is focused on the LCA of their product. It does not appear that ClubZero has a detailed climate strategy or it is not readily accessible. This is likely due to their small size.
		GC 4		■		It does not appear that ClubZero has a detailed sourcing strategy, and it is unclear where the cups are manufactured and washed. This information is potentially missing due to their small size, or they may still be deciding who their long-term suppliers may be.
		GC 5			■	ClubZero won Ellen MacArthur Foundation's New Plastics Economy Prize in 2017. As a result, they participated in a year-long accelerator program supported by the US innovation hub, Think Beyond Plastic. This is an impressive prize and shows the strength and acceptance of ClubZero as a sustainable solution to ending plastic waste in the reuse market at large. Winning this prize demonstrates EMC's stamp of approval. They are also backed by R/GA, atomic, and Seedcamp. Although these organizations are not specific to plastic waste mitigation, they are still notable and provide credibility. There is also mention of partnerships with Closed Loop Fund and IDEO on their website, well established circular economy and design firms. However, they do not detail the nature of their partnership and only mention it as part of their pilot lunch with Starbucks and McDonalds in Palo Alto, CA. ClubZero has established relationships and partnerships with global retailers such as McDonalds, Starbucks, Coca-Cola, and Nestle which also provides credibility and insight into where and how they plan to scale and general market interest.
	ESG Overall			■		For ClubZero's current size their ESG performance is good. Improvements still need to be made in standardizing reporting and refining their sourcing strategy however.
Firm Level Sustainability Overall				■		At the firm level, ClubZero has made progress highlighted by the Ellen MacArthur Foundation's New Plastic Economy Prize in 2017, however several improvements still need to be made. These improvements range from standardizing processes, clarifying partnerships, and aligning to ESG platform standards.
Innovation / Technology Level Characterization & Readiness	Innovation / Technology Classification & Screening	SC 1			■	By comparing the equivalent consumption of different cups, the LCA establishes several break-even points for each kind of cup. According to their data, the cup can be used at least 132 times, which is higher than break-even points of all disposable cups considered in this LCA study. Therefore, the life cycle of a ClubZero product is expected to have lower energy and water use than disposable cups over its lifetime (see breakeven points below in figure 13).
		SC 2			■	The cup is made of LDPE and PP, which are commonly accepted by most recyclers as the source of post-consumer resin, and both have robust recycle markets.
		SC 3			■	The breakeven number of reusing is 72 vs. paper/PS cups at 1% recycle rate and 132 at 80% recycle rate; 100 vs. EPS cup; and is better than ceramic until about 2000 uses.
		SC 4		■		Environmental impact of the reuse scheme will decrease specifically in washing and transportation as renewable energy becomes more widespread.
	Innovation / Tech Classification & Screening Overall				■	ClubZero shows evidence of being able to replace 132 single use cups and further is made of LDPE and PP which are commonly accepted by recyclers. Depending on the conditions of washing in the reuse scheme the environmental impact of the solution may deteriorate.
	Scale of Impact	GC 6			■	The company's cup consists of PP and LDPE, but the comparable alternatives are paper cups with PE/PLA, EPS, and ceramic. Ultimately, this is a plastic solution that will displace a number of single-use products, with the displacement of plastic lids on paper cups likely the most prevalent (see table below for more detail). The targeted displacement is a common and ubiquitous plastic. Coffee cup lids may be a waste stream that could experience lower rates of recycling relative to other plastic products.
		GC 7			■	These numbers may be compared to the ClubZero specifications of 49.3g of polypropylene and the lid from 22.03g of low-density polyethylene. It appears over the lifetime of 132 uses, ClubZero reduces plastic waste when compared to these cup alternatives. It is important to note that as the recycling rate of paper cups goes up, the attractiveness of ClubZero goes down. For example, according to the LCA data, paper cups become favorable over ClubZero in total emissions once the recycling rate of paper cups reaches 80%. However, it is well known the recyclability of these kinds of cups is difficult as they are blended materials (paper and plastic liner). Besides comparing the performance of ClubZero with other competitors, we need to consider the extent to which a given innovation will scale within the broader economy to fully investigate the sustainability of ClubZero's service. ClubZero has provided the material information of their reusable cups and compared them with their competitors (Table 6). It is estimated that 50 billion disposable coffee cups are consumed in the US every year, and if all disposable cups are replaced with ClubZero's product, 0.183 Mt of plastic can be reduced per year which accounts for around 0.3% of total US plastic consumption.
	Scale of Impact Overall				■	If successfully scaled, ClubZero has the potential to reduce 0.183 Mt of plastic per year, which accounts for around 0.3% of total US plastic consumption.
	Market Readiness	GC 8		■		The ClubZero product provides similar or superior technical performance to disposable coffee cup alternatives. It is not clear how overall product performance may change or degrade over 130 uses. The cups are installed with RFID chips to track them. It is not clear if the RFID chip will degrade over the lifetime of the product.
		GC 9		■		ClubZero requires installed physical infrastructure of cup collection points at locations that are convenient for consumer drop-off. The innovation also requires collection, transportation, and cleaning infrastructure in order to reclaim and reuse the cups.
		GC 10		■		ClubZero requires behavioral change from consumers in order to be effective. In order for sustainability benefits to be realized, consumers must return the cups for reuse a sufficient number of times. Currently, incentive/penalty structures are being used to encourage consumers to return their cups at collection points in a timely manner.
	Market Readiness Overall			■		While ClubZero provides a very similar function to existing disposable cup alternatives, barriers such as infrastructure and changing consumer behavior inhibits the market from being fully prepared.
Innovation / Technology Level Characterization & Readiness Overall					■	ClubZero's technology has clear potential to reduce a material amount of plastic waste if effectively scaled. Inhibiting scaling are barriers including consumer behavior, infrastructure, and cup reclimation.

Systems Level Assessment	Circular Economy	GC 11		■		According to the sustainability report, the cup is a recyclable (assumed 90% recyclable) petroleum product with RFID chips.
		GC 12		■		Further investigation is required to determine that recycling (90% of material claimed to be recycled) of the cups at end of life occurs.
	Circular Economy Overall			■		The need for further investigation on the recyclability of the product inhibits the solutions assured contribution to a circular economy.
	Certifications	GC 13	■			CupClub has not given any information about their certifications, but it doesn't mean that they are not qualified as a sustainable product because the product is still in development and practice. According to their sustainability report, it will be helpful if they can get following types of certifications: Business strategy - B Corp Energy Savings - Energy Star Environmental Management - ISO14000 GHG Emission - Product Carbon Footprint Label, Science Based Targets Initiative, and Climate Neutral Certified Water Savings - WaterSense Certification Plastic Recycle - Post Consumer Resin (PCR), Mass Balance Certification, Recycled Claim Standard (RCS), and Global Recycled Standard (GRS) Quality assurance - Recycled plastic Component recognition
	Certifications Overall		■			Cup Club should consider attaining certifications from the above list.
	LCA Quality	LCA QC 1			■	Study conducted by Giraffe Innovation Ltd, which is one of the UK's top green businesses due to its extensive experience in delivery of a wide range of sustainability driven projects.
		LCA QC 2			■	A 3rd party peer review was conducted during July, 2018, which follows "[p]rocess intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment" ((ISO 2006b), section 3.45).
		LCA QC 3			■	System boundaries are clearly defined and appropriate (Figure 12), which follows "consecutive and interlinked stages […] from raw material acquisition or generation from natural resources to final disposal" ((ISO 2006b), section 3.1). Functional units is sufficient, though somehow arbitrarily defined as 132 uses (expected useful life of CupClub cup), which follows "Quantified performance of a product system for use as a reference unit" ((ISO 2006b), section 3.20)
		LCA QC 4		■		Uncertainty in the input data used in an LCA means uncertainty in the results; an uncertainty assessment demonstrates the extent to which data uncertainty influences the outcome or conclusions of a study. Data uncertainty can be compounding, so the influence of parameters should be considered together. Sensitivity assessment, on the other hand, considers how a given parameter changes the results of the study. A study is typically conducted around a specified set of conditions - for example, transportation distances, recycling rates, number of reuses - but variation in these are likely. A good sensitivity assessment will offer information about which parameters most strongly influence environmental performance and therefore which parameters require the most attention in business development and implementation. For example, a reusable packaging system may show favorable life cycle results in comparison to a single-use alternative for GHGs. A sensitivity assessment will indicate when the reusable system will be less favorable as transportation distances increase, such as for return trips for pooled washing.
		LCA QC 5			■	To check data quality, the data quality indicators have been clearly defined in the report based on ISO 14044 Section 4.2.3.6.2. Each information is measured by these matrices and deemed sufficient. Although most data have been measured by the indicators, the conclusion and interpretation of the LCA report does not directly reflect how the data quality measurements affect the final results.
	LCA Overall Quality				■	The quality of the LCA is of high quality as evidenced, by the clear statement of system boundaries and processes to check data quality
	LCA	GC 14			■	Yes, CupClub has provided a LCA report which includes comparative analysis of the environmental impacts of CupClub against alternative disposable single use coffee cups and a reusable ceramic cup. See sub-criteria guidance for "Assessing the Quality of Life Cycle Assessment", below.
		GC 15			■	The company claims its product could have 50% less carbon dioxide emissions, which is quite a strong and measurable indicator in the mission statement. The company uses life cycle assessment to demonstrate their defined and measurable sustainability goal
		GC 16	■			Cup Club has not offered a review of literature.
	LCA Overall				■	It is very impressive that CupClub has completed an LCA, especially one of such high quality. The results from the LCA are promising, however, the lack of review makes it challenging to fully validate.
	Health and safety, regulations, future trends	GC 17	■			No publicly available data is available regarding community engagement or potential environmental justice issues.
		GC 18			■	Since CupClub is a replacement for a single-use option, this business model avoids risks associated with regulation or bans on single-use cups specifically. Areas where there is a tax on single use cups or a deposit return scheme infrastructure in place for reusable items will be advantageous for CupClub, often called the latte levy. For example, Berkeley, CA placed a $0.25 tax on disposable cups which would offer CupClub an advantage in the marketplace based on cost.
		GC 19			■	The changing regulatory environment surrounding single-use plastics is most likely to impact the viability of this product. In particular, single-use plastic bans may make adoption of CupClub more attractive to retailers. Further, greening of the grid would make CupClub an even more attractive option.
	H&S, Regulations, Future Trends Overall				■	The changing regulatory environment paired with existing return infrastructure points towards CupClub being well positioned in the future.
Systems Level Assessment Overall					■	CupClub offers a solution that has been tested and appears to meaningfully contribute to a reduction of plastic waste during its use phase and highly recyclable at its end of life.
Investment Decision					■	Overall assessment for this section is that CupClub has the potential to improve the circular economy of the coffee cup industry and reduce environmental impacts and plastic waste. Nevertheless, many of the sustainability assumptions are contingent upon consumer buy-in and whether the reuse rates assumed in the life cycle assessment reflect realistic collection conditions.

Figure 14: ClubZero PRISET Evaluation Summary.

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CENTER FOR SUSTAINABLE SYSTEMS
UNIVERSITY OF MICHIGAN

School for Environment and Sustainability, 440 Church Street, 3012 Dana Building, Ann Arbor, MI 48109-1041
734-764-1412 | css.umich.edu