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Research article

Exploring Backcasting as a Tool to Co-create a Vision for a Circular Economy: A Case Study of the Polyurethane Foam Industry

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Abstract

The pursuit of Circular Economy (CE) principles in industrial activities is crucial for mitigating environmental impacts, particularly in relation to plastic consumption and waste. While desirable, such a transition is incredibly challenging for many industries. Using the polyurethane (PU) foam industry as a starting point, a participatory planning process called backcasting was used to engage diverse stakeholders and explore the potential for CE implementation and transition. Usually applied in policy-making contexts, this study used a particular approach ("ABCD-method") to facilitate a workshop of industry representatives from across the PU foam value chain: recyclers, chemical suppliers, manufacturers, academia, and governments. Through the process, participants discussed, developed and agreed upon 78 CE Pathways, categorizing these as short-, mid-, and/or long-term priorities, and assigning them to respective and appropriate PU foam value chain members. These co-created CE Pathway priorities, such as the development of industry-wide material specifications, simplified chemical formulations, and innovation in feedstock sourcing, may contribute to increased industry awareness about potential opportunities for transition to the CE within PU foam value chain. CE Pathway priorities from this work are informing the strategic roadmap for the PU foam industry's transition to CE. Further, this work suggests the efficacy of participatory backcasting as a potential method for facilitating voluntary industry discussion and visioning across diverse sectors and value-chains.

Keywords: Circular Economy, Backcasting, Polyurethane Foam, End-Of-Life Management, Sustainability, Transition Strategy, Stakeholder Engagement

The intricate relationship between industries and the environment has become increasingly important, motivated by concerns about environmental damage, resource scarcity, and changing climate (Lieder & Rashid, 2016). The prevailing linear economy, characterized by "take-make-dispose", is known to exacerbate resource challenges and environmental consequences (Gallucci et al., 2019). Despite efforts to improve resource efficiency through technological and design interventions, our consumption-driven economic systems still incur waste and losses across the value chain (MacArthur et al., 2015). The circular economy (CE) concept has emerged as a promising solution to address some of these challenges, encompassing various innovations and adaptations that range from waste management (Tomić & Schneider, 2020) to realized, closed-loop material flows within the entire economic system (Yuan et al., 2006) and the achievement of industrial economy by regenerative design (MacArthur, 2013).

Despite significant interest, challenges persist in implementing the CE, and this is especially evident in the polymer industries. The CE framework offers a lens through which industry members can consider and develop new strategies for technological advancement, value chain restructuring, and stakeholder collaboration. Technological solutions and system connectivity play vital roles in successful implementation of CE solutions;

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Simultaneously, industry stakeholders are actively integrating CE principles, i.e., by embracing design for durability and repairability. The optimal path towards CE may not be clearly known, but there are diverse and extensive observed efforts within individual organizations working to implement CE, providing insight, information, and new lessons that may help to smooth and streamline transitions that can occur at scale, across value chains, and involving multiple organizations.

Polyurethane (PU) is the sixth most widely used polymer in the world (Britt et al., 2019), with its foam-form serving a broad range of applications including furniture, automotive interiors, insulation, and packaging. Due to the complex chemical structure of this polymer, and its large, bulky form, end-of-life management of PU foam products can be complicated, with a significant portion of end-of-life PU foam managed through landfilling and incineration (Heiran et al., 2021; Yang et al., 2012). The PU foam value chain, consisting of industry members across diverse processing, manufacturing, distribution and sales activities, is being influenced by the European Union's promotion of a transition to the CE and the use of eco-friendly plastics (Mariotti et al., 2023). This influence is prompting industry members and academic researchers to explore innovative opportunities and transformations throughout the entire lifecycle of PU foam, from the careful selection of raw materials, the responsible management at end-of-life, and the recycling of PU into new feedstock chemicals (Cornille et al., 2017; Kreye et al., 2013). Increasing interest in emerging technologies, including chemical recycling, are receiving attention and interest given their potential to facilitate a CE for PU. However, implementing these new technologies, and the supporting infrastructure and behavior change requirements, will require substantial alignment between diverse, often disconnected value chain stakeholders.

This study examines the following research questions: How might a tool commonly used to support collaborative policy-making, e.g., participatory backcasting, be adapted to facilitate the co-creation of shared vision, alignment, and priorities for a CE transition amongst diverse industry stakeholders from diverse sectors within the PU foam industry? Further, what insights are revealed through the application of backcasting regarding the challenges, opportunities, limitations, and innovative domains for implementing CE transitions within the PU foam industry, and how do these insights inform the development of a coherent, strategic framework for achieving circularity within the industry?

Using the PU foam industry as a starting point, this study also considers the use of backcasting for its potential to effectively engage diverse stakeholders and explore the potential for CE implementation and transition in other complex industry value chains. The following section presents the theoretical framing of product lifecycle as the basis for understanding opportunities for collaboration and co-creation within the study, with subsequent sections presenting the methodology, results, and discussion, respectively.

1. THEORETICAL FRAMING

Given that CE transition requires systems-thinking and a grounded understanding of material and product flows, a visual product lifecycle framework was used to establish a common understanding and point of reference to support industry stakeholders when considering opportunities for increased circularity. within their operations and supply chains. As summarized in Figure 1, each product lifecycle stage (Figure 1[A]) was framed to correspond with relevant value chain stakeholder groups from the PU foam industry (Figure 1[B]). Through this approach, stakeholders were provided insight and opportunity to more effectively engage in discussion and envisioning of future scenarios.

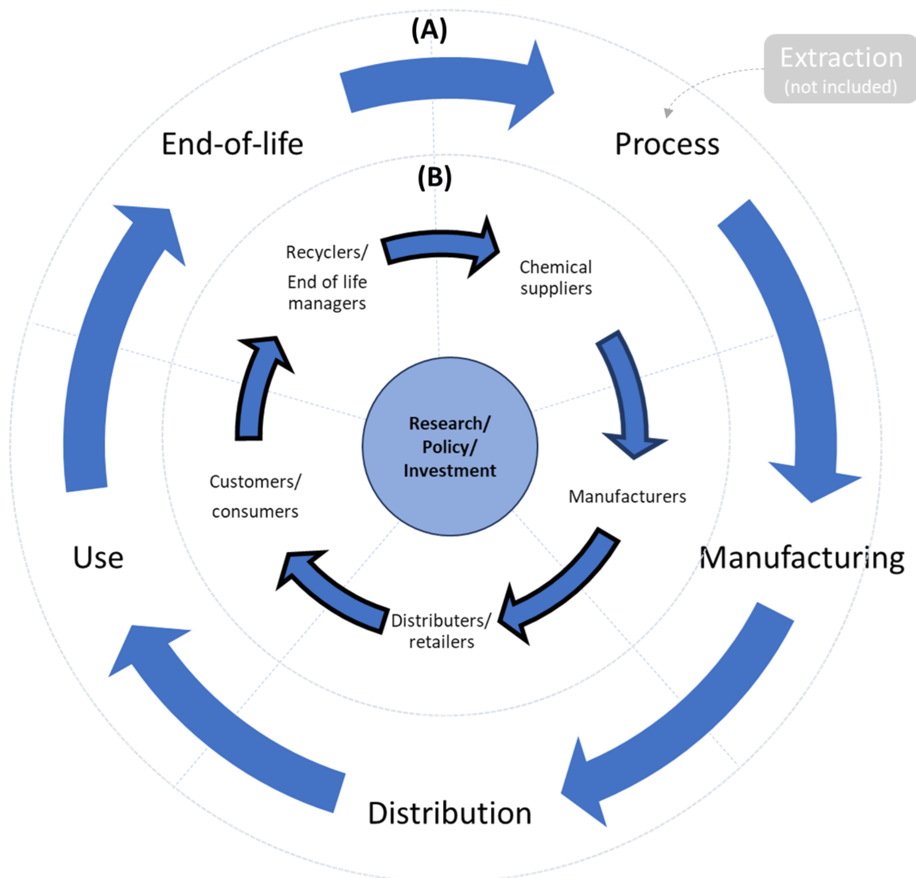

Figure 1. Comparative Framing of Lifecycle Stages Relative to Value Chain Activities: The Outer Ring [A] Reflects Conventional Stages of the Product Lifecycle, and the Inner Ring [B] Reflects the Corresponding PU Foam Value Chain Stakeholder Groups Engaged in That Lifecycle Stage. Themes Tied to Research, Policy and Investment Cut across Both Lifecycle and Stakeholder Considerations. Stakeholders Engaged in the Extraction of Inputs to Chemical Processing Activities Were Not Included in the Study, However the Procurement and Sourcing of Inputs by Chemical Suppliers Was Included in the Scope (e.g., Alternatives to Primary Petrochemicals)

Although the transition to CE is not currently regulated within the U.S., many industry members are exploring CE opportunities as voluntary initiatives (Sarkis et al., 2021). In the U.S., the transition to a future CE for the PU foam value chain (and others) is unlikely to be driven by regulations or compliance measures, but instead through voluntary, co-created industry priorities, values, and initiatives. However, voluntary initiatives that extend beyond the boundaries of a single organization can be difficult to implement, coordinate, evaluate, and assure. Compounding this challenge is the fact that many organizations lack comprehensive understanding of the diverse processes and practices that may enable CE, and they lack communication and relationships with other organizations located up- and downstream in their value chains who are integral to achieving CE. Before voluntary initiatives and strategies can be developed, there is a critical need to establish common language, visions, and understanding of the desired future and the variety of pathways through which it could be achieved.

Backcasting is often used as a method for approaching themes of "sustainable futures" and "sustainable development", offering a proactive and strategic approach to align development with environmentally and socially responsible goals. Backcasting refers to a participatory and collaborative process of envisioning the desired future or success, clarifying the current state conditions, and then identifying the diverse strategic pathways needed to achieve the desired future. (Bibri, 2018). This method is employed when there is a belief that the current developmental trend may be insufficient; in this case, backcasting can be utilized to envision and plan for a more desirable future (Robinson, 1990). Participatory backcasting is commonly used as a public policy tool aiding in the co-creation of community visions and initiatives where diverse stakeholder interests are involved (Dixon et al., 2018; Mahmoud et al., 2021). Accordingly, this study explores whether a collaborative participatory backcasting method commonly used in public policy settings could be adapted to meaningfully engage diverse value chain stakeholders within the PU foam industry, including for-profit companies, non-profits, and government organizations involved at each stage of the life cycle of a PU foam product.

This study specifically adopts the operational protocol of the Framework for Sustainable Development (FFSD) (Broman & Robèrt, 2017), using the A-B-C-D backcasting methodology to ensure comprehensive analysis and strategic planning (Ny et al., 2006). The A-B-C-D method is a practical use of backcasting (Wieliczko, 2017) that encompasses a structured sequence of four distinct stages: Awareness and Defining Success (A), Baselining the Current State (B), Creative Solutions (C), and Decide on Priorities (D) (Table 2). In Step A (awareness and visioning), the characteristics and conditions of an envisioned future are elaborated. This is followed by Step B (Baseline-setting), where current state relevant conditions are identified. Step C (Creative Solutions), creative requirement and solutions are developed through collaborative interdisciplinary discussions and brainstorming to complete the transition from the current state to the agreed desired future in Step A. In step D (Decide on priorities), the priorities are chosen from the developed list of solutions and requirements. Effectively, diverse participant views about the desired future and the current state conditions and challenges are documented; collaborative processes then progress to envision the possible pathways, priorities, and requirements that each stakeholder may need to complete the transition from current state to desired future. In short backcasting is the process of positioning of success then looking in the rear-view mirror of how this success was achieved. Because the process is collaborative, participatory, and establishes buy-in and consensus-building, the co-created priorities and pathways reflect viable possibilities and create a greater sense of transparency and accountability amongst participants.

2. METHODS

The research team recruited participants representing different parts of the PU foam value chain who were attending the Center for Polyurethane Industry (CPI) Technical Conference in October 2023; additional participants were approached through the personal networks of PU foam industry members and leaders who offered to assist. Data was collected via a two-day hybrid virtual and in-person workshop in Tempe, Arizona, that hosted 43 workshop participants representing PU foam stakeholders, including recyclers (4.7%), chemical suppliers (39.5%), manufacturers of PU foam /products (23.3%), academia (25.6%), and governments (6.9%).

During the workshop, participants were guided through the sequenced A-B-C-D backcasting method (Table 1), utilized to foster an inductive approach to problem-solving and strategy development (Ny, 2009) methodically progressing through each stage, the participants benefitted from a structured framework that allowed for comprehensive analysis, creative thinking, and informed decision-making. This collaborative process facilitated a collective exploration of pathways to sustainable development, ensuring that the resultant strategies were both robust and aligned with the overarching goals.

Table 1. Overview of Workshop Activities Aligned With A-B-C-D Methodology Steps (Adapted From Ny, 2009)

Backcasting steps	Workshop Activity	Outcome or Output
A: Establish awareness	(i) Participants were provided with an informational presentation about CE. (ii) Participants discussed the aspects and conditions of a realized circular economy for PU foam.	→ Established common knowledge and terminology for participants. → Clarified the mechanisms by which circularity may be achieved by different stakeholders, and across different PU foam products and sectors.
B: Baseline current state	(i) Engaging the individuals to involved participant discussion of the current state to share the experience, observation and perception about particular barriers and enablers within the industry.	→ Individually documented list of barriers, opportunities, actors, and enablers for CE in PU foam industry.

C: Create the solution	(i) Collective visioning of future state of achieved CE, as experienced by each value chain stakeholder group. (ii) Group discussion of requirements, challenges, barriers, and enablers to achieve the vision. (iii) Review and assignment of **CE Requirements** (output of C(ii)) by research team into **CE Pathway** categories.	→ Comprehensive, co-created list of **CE Requirements** for each stage of PU foam value chain. → Inductively developed categories/themes of strategic **CE Pathways.**
D: Decide on priorities	(i) Individual ranking of top 5 **CE Pathways** for each value chain stakeholder group. (ii) Group collaboration to rank top 3 prioritized **CE Pathways** in each value chain stake holder group (iii) Timeline dedication to the prioritized pathways.	→ Individual selection of priority **CE Pathways** for each value chain stakeholder group. → Co-created group selection of priority **CE Pathways** for each value chain stakeholder group. → Collaborative assessment of realistic implementation timelines for priority **CE Pathways.**

On the first day, in Step A (awareness and visioning), Individual participants received an informational presentation on CE from the research team and they were asked to describe and elaborate on the characteristics and conditions they believed would and should be part of an "achieved" future CE for PU foam. While participants did not develop the vision of circular economy (it was given), they were tasked to describe what a circular economy for PU foam in the future would look like. This work was followed by Step B (or Baseline-setting), in which current state relevant conditions, barriers, and anticipated enabling conditions were identified and discussed. Participants were then asked to use a digital collaboration whiteboard application to document their personal responses to prompted questions regarding main stakeholders, current enablers, and particular barriers, related to the circular economy for the polyurethane foam value chain. These questions focused on identifying stakeholders, potential opportunities, and critical barriers associated with implementing CE initiatives in the PU foam industry. The aim of this exercise was to elicit a range of perspectives and ideas from diverse PU foam value chain stakeholders. Effectively, it helped to reveal and clarify diverse participant views about the desired future and the current state conditions and challenges.

For Step C (or Creative Solutions), collaborative interdisciplinary discussions and brainstorming were used to envision the possible creative pathways, and requirements that may be needed by each stakeholder to complete the transition from the current state (e.g., relatively linear systems) to the agreed desired future (e.g., circular economy, as established in Step A). participants were divided into eight groups that were preassigned to ensure a mix of chemical suppliers, manufacturers, distributors, retailers, consumers, end-of-life managers, local governments and policy makers, and academia. Their task was to, through discussion, collaboratively envision an ideal future state for the circular economy (CE) that would be viable for the diverse stakeholder groups. Participants were presented with a future scenario in which a fully circular PU foam industry had been achieved; based on this scenario, groups were asked to reflect and consider how this scenario would manifest and be experienced by each of the stakeholder groups, reflecting six distinguished stages of the product lifecycle i.e., via backcasting.

Groups were prompted to imagine an achieved CE and describe how material and product flows, relationships, and business models might manifest for each stage of the lifecycle, and for the PU foam value chain stakeholder groups involved at that stage. During these collaborative discussions, participants documented the ideas regarding the essential needs and requirements of a successfully implemented circular economy using digital whiteboards. This included identifying any challenges and opportunities specific to each stakeholder group and lifecycle stage (hereafter called "CE Requirements"). To encourage cross-pollination of ideas and broad contribution opportunity, the groups were also asked to reflect on, evaluate and provide critical perspectives about the CE Requirements that had been proposed by other groups on the digital whiteboards.

Following the conclusion of Step C, the research team systematically examined the multitude of CE Requirements developed by the participants, and inductively categorized these based on emerging and observed common themes (hereafter called "CE Pathways").

From the list of creative CE Pathways, the collective group then used ranking and voting processes to collectively decide on the priority actions for each stakeholder group to meaningfully advance towards the envisioned CE in Step D (Decide on priorities). This step encompassed two distinct stages aimed at capturing both individual and collaborative perspectives. First, drawing from the CE Pathways list generated from Step C, participants were instructed to individually select and rank what they believed to be the most important five CE Pathways at each stage of the value chain. This task was facilitated through an online survey, which prompted participants to rank the identified CE Pathways in terms of priority from first (most important) to fifth (the least). Priority scoring was quantified using a five-point scale, in which the "most important" (Rank 1) CE Pathway received 5 points, and the "least important" received 1 point and tallied for each CE Pathway.

Following individual priority ranking, groups were reconstituted and assigned the task of collaboratively reaching consensus on their three priority CE Pathways (unranked). To ensure clarity and prevent any confusion, these new groups were provided with an online survey presenting the same content in an alternate format. Participants were then tasked to discuss and reach agreement on the three priority CE Pathways within each value chain category.

As a final task, groups were asked to organize their selected priority CE Pathways into three implementation timelines: short-term (<5 years), mid-term (5-10 years), and long-term (>10 years). This was done to stimulate and encourage participants to consider the temporal dimension of their priorities and align them cohesively with their envisioned outcomes for the short, mid, and long-term periods.

3. RESULTS

The results obtained from the data collected in Steps A and B of the backcasting method highlighted a total of 84 key barriers that are currently obstructing the transition to a Circular Economy (CE) within the PU foam industry (Figure 2). The full set of identified CE barriers developed by workshop participants are presented in Appendix 1, Table A1. Among these challenges, technological barriers emerged as the predominant concern, accounting for 47.6% of the identified barriers. These challenges are largely related to the nature and/or characteristics of PU foam and the products in which it is commonly used (e.g., mattresses, furniture). These products are difficult to integrate into existing circular economy solutions, i.e., because they are large, bulky, and costly to transport for refurbishment or recycling; and because they are often viewed to be intimate products and thus may be unappealing for direct reuse." Infrastructure-related obstacles constituted 17.9% of the total barriers, and primarily pertained to the lack of efficient reverse-logistics systems and cost implications associated with scaling-up recovery and recycling infrastructure. Market barriers, which encompass issues related to the affordability of primary, non-recycled feedstocks and inputs to PU foam manufacturing, and the substantial variability and diversity within PU foam supply chains (e.g., not standardized), constituted 14.3% of the identified barriers. These challenges were tied to a strong economic preference for the lower-cost, more accessible primary feedstocks to PU foam, relative to recycled-content which is more difficult to integrate, and more expensive. Notably, the category of policy barriers, albeit the smallest at 9.5%, revealed the most diverse range of insights. This category primarily relates to the absence of comprehensive policies aligning stakeholders across the value chain.

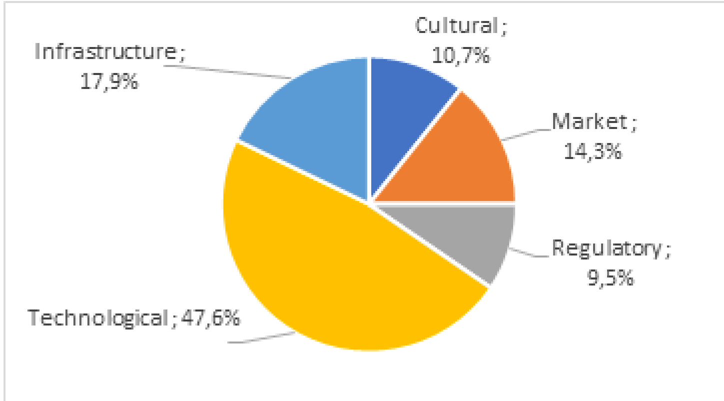

Figure 2. Categorization of Identified CE Barriers, Based on Perceptions and Experience of Workshop Participants

These barriers stimulated subsequent group discussions, which collectively generated a list of 348 CE Requirements encompassing specific actions and interventions needed to overcome barriers and achieve CE across each of the value chain stakeholder groups (Table 2). The highest share of CE Requirements was attributed to PU foam Manufacturers and Chemical Suppliers, each being assigned 18.1% of the total. However, all stakeholders along the value chain were identified as having a critical role to play in terms of CE Requirements: Consumers/Customers and Recovery/Recycling agents were assigned 16.7%, respectively; Distributor/Retailers were assigned 14.1%; and collective Policies/Research/Investment stakeholders were assigned 16.3% (Table 2).

Inductive analysis and categorization of the 348 CE Requirements integrated elements of engaged scholarship (Bansal & Corley, 2011) and systematic combining (Dubois & Gadde, 2002), and resulted in the emergence of 78 distinct CE Pathway themes/categories. The full list of CE requirements and corresponding pathways for chemical suppliers, PU foam manufacturers, and recovery and recycling stakeholders, developed in collaboration with workshop participants, are outlined in detail in Appendix 1, in Tables A2, A3, and A4, respectively. The greatest diversity of ideas (n=20) emerged for the Policies/Research/Investment stakeholders. This accounts for almost 25% of the total CE Pathways generated, and reveals the continuing need for new knowledge, resources, technology, and guidance to support a CE transition. Table 2 presents an overview of the distribution of CE Requirements and CE Pathways for each value chain stakeholder group.

Table 2. Distribution of CE Requirements and CE Pathways

Value chain stakeholder groups	**CE Requirements**		**CE Pathways**
	#	**%**	**#**
Chemical Suppliers	63	18.1	11
Manufacturers	63	18.1	13
Distributor/ Retailers	49	14.1	10
Consumer/Customers	58	16.7	11
Recovery/ Recycling	58	16.7	13
Policies/ Research/ Investment	57	16.4	20
Total	**348**	**100**	**78**

The definitions and resulting quantitative individual ranking scores for the CE Pathways are presented for Chemical Supplier value chain stakeholders (Table 3), Manufacturer value chain stakeholders (Table 4), and Recovery/Recycling value chain stakeholders (Table 5). Additional discussion is presented for the CE Pathways receiving the highest priority ranking score within the category.

According to quantified individual priority ranking, there are two CE Pathway priorities that Chemical Suppliers to the PU foam industry should be focusing on. First, collaborating downstream (with manufacturers) to clarify material specifications and explore alternative applications for materials containing recycled content (SM2), which received a score of 59 (Table 3); Second, collaborating upstream (with recyclers) to improve collection and diversion of materials to best suit recycled materials requirements and application needs, with a score of 58 (Table 3). This reflects recognition of the opportunity for Chemical Suppliers to the PU foam industry to act as a lynchpin in the system for exploring where circular feedstocks/inputs may be viable. This ties logically and appropriately to the third priority for Chemical Suppliers, which is to drive innovation in feedstock sourcing and material development (e.g., biomaterials, pre-consumer scrap) (SM5), with a score of 47 (Table 3). This is also clearly aligned with SM9, collaboration with research teams and institutions investigating chemical recycling potential.

Table 3. Description Of, and Individual Priority Ranking Scores for the CE Pathways Identified for Chemical Suppliers to the PU Foam Industry: Reflects the Number of CE Requirements That Are Addressed by Each CE Pathway. CE Pathway IDs SM1, SM2, and SM5 Received the Highest Collective Priority Ranking Scores

ID	CE Pathways identified for Chemical Suppliers to the PU foam industry	Number Of CE Requirements Addressed	Priority Score
SM1	**Collaborate upstream (with recyclers) to improve collection and diversion of materials to best suit recycled materials requirements and application needs**	**8**	**58**
SM2	**Collaborate downstream (with manufacturers) to clarify material specifications and explore alternative applications for materials containing recycled content**	8	**59**
SM3	Mitigate uncertainty within the system through innovative contract arrangements/agreements	10	9
SM4	Vertical integration in upstream supply, e.g., add/expand into secondary refining and purification activities; add/expand into recovery/recycling activities	3	29
SM5	**Innovation in feedstock sourcing and material development (e.g., biomaterials, pre-consumer scrap)**	**9**	**47**
SM6	Establish certification criteria and certification process related to recycled content	4	32
SM7	Removal of contaminants that may be present within recycled materials/output materials	2	37
SM8	Explore options and possibilities that may exist for harmful substances and/or obsolete materials.	2	2
SM9	Collaborate with research teams and institutions investigating chemical recycling potential	2	42
SM10	Transition operations and facilities to be energy efficient, renewable energy and net-zero goals.	6	18
SM11	Voluntary adoption of green chemistry best practices and reduce use of harmful substances.	4	19
_	Other and Non- related ideas	5	__

The prioritized pathways as perceived by individuals within the PU foam manufacturers' value chain group (Table 4) indicates that within this category, coordinating with suppliers to establish clear circular material specifications and requirement (M4) holds the highest priority with a score of 43. The second-highest priority, scoring 36, pertains to development and implementation of material design requirements for circularity, encompassing aspects like design for degradation, controlled degradation, and substance/material separation (M6) (Table 4 Individual participants received an informational presentation on circular economy from the research team.). Also, individual participants focusing on simplifying material formulations to enhance end-of-use, end-of-life management, and recycling feasibility, as the third priority in this category, with a score of 32 (Table 4).

Table 4. Description Of, and Individual Priority Ranking Scores for the CE Pathways Identified for PU Foam Manufacturers: Reflects the Number of CE Requirements That Are Addressed by Each CE Pathway. CE Pathway IDs M4, M5, and M6 Received the Highest Collective Priority Ranking Scores

ID	CE Pathways identified for PU foam Manufacturers	Number of CE Requirements Addressed	Priority Score
M1	Pre-consumer (production) scrap recovery and cycling (not down-cycling or downgrading)	4	8
M2	Communicate with and manage customer/user expectations regarding the circular product (e.g., performance, color, longevity)	4	12
M3	Clear product labeling and/or product identification (e.g., digital passport technology) regarding material composition and source information	8	25
M4	**Coordinate with suppliers to establish clear circular material specifications/requirements**	3	**43**
M5	**Simplify material formulations to make end-of-use and end-of-life management and recycling easier and less costly**	**3**	**32**
M6	**Develop and implement material design requirements for circularity (e.g., design to degrade; controlled degradation; substance/material separation)**	4	**36**
M7	Develop and implement design requirements for product circularity (e.g., design for disassembly; design for durability; design for environment)	7	26
M8	Develop and implement product-appropriate recovery and circularity systems	4	23
M9	Collaborate with and grow upstream supply chain to increase circularity opportunities and compatibility of inputs (e.g., new sources, new feedstocks)	4	28
M10	Collaborate with and grow downstream supply chain to facility circularity opportunities (e.g., streamlined recovery channels, purification and secondary refining of recycled feedstocks; removal of harmful substances)	2	28
M11	Manufacturer leadership to design and manage collection systems for end-of-use/end-of-life products	8	22
M12	Sustainable facility transitions to renewable energy and energy efficient infrastructure and equipment	2	11
M13	Growth and innovation of niche value-add activities needed for circular systems	3	6
_	Other and Non-related ideas	6	_

Finally, for stakeholders engaged as Recovery/Recycling of PU foam products, the establishment of widespread, local collection infrastructure and consolidation points, as well as collaborating with other stakeholders to effectively educate and communicate about local end-of-life options (RR4) is the top priority with a priority score of 47 (Table 5). Interestingly, participant stakeholders in the workshop from this stakeholder group were already actively providing local collection infrastructure and consumer information. That the collective of workshop participants, representing the PU foam value chain, identified this as the top priority, reflected the lack of clarity and understanding of the current state of end-of-life product management. It was apparent that this lack of understanding also involved inaccurate assumptions about the resources, authority, and capacity of this stakeholder category, e.g., to increase scale and access to local collection sites. In the current state, these most Recovery/Recycling stakeholders operate as government entities or non-profit organizations, and typically lack formal revenue streams while still being expected to bear the burden of cost, logistics and management in the absence of regulation in most U.S. states. In addition to a focus on local collection infrastructure, PU foam product Recovery/Recycling stakeholders were tasked to prioritize coordination with manufacturers and material suppliers to clarify the most important labeling requirements needed for disassembly, recycling, and other end-of-life management options (RR7) (Table 5). This information was identified as important information for manufacturers who wanted to engage in more circular product design that considered improved recycling options at end-of-use and end-of-life. Further, recognizing that current recycling technology for PU foam products is largely focused on mechanical processes, Recovery/Recycling stakeholders were tasked to engage in market development for known by-products of chemical recycling (e.g., urea, primary amines, isocyanates) to facilitate circularity options for both material and chemical substance flows (RR1).

Table 5. Description Of, and Individual Priority Ranking Scores for the CE Pathways Identified for PU Foam Product Recovery/Recycling Stakeholders: Reflects the Number of CE Requirements That Are Addressed by Each CE Pathway. CE Pathway IDs RR1, RR4, and RR7 Received the Highest Collective Priority Ranking Scores

ID	CE Pathways Identified for PU Foam Product Recovery/Recycling Stakeholders	Number of CE Requirements Addressed	Priority Score
RR1	**Market development for by-products of chemical recycling (e.g., urea, primary amines, isocyanates)**	**2**	**34**
RR2	Market development for by-products/outputs of mechanical recycling	2	27
RR3	Establish dedicated ‘pure’ collection streams (e.g., hotels, universities, pre-consumer/production scrap) that can reduce loss/contamination in the system	7	27
RR4	**Establish local collection infrastructure and consolidation points and coordinate with other stakeholders to effectively communicate and educate about local end-of-life options**	**4**	**47**
RR5	Streamline/optimize networks for pre-treatment, collection, and transportation of end-of-life products for recycling.	9	30
RR6	Develop and communicate a portfolio of circular economy options, including mechanical and chemical recycling, and reuse.	1	27
RR7	**Coordinate with manufacturers and material suppliers to clarify the most important labeling requirements needed for disassembly, recycling, and other end-of-life management options.**	**1**	**35**
RR8	Ensure broad-scale accessibility and convenience of collection points for customers/users	3	26
RR9	Educate customers/users about the structure and properties of the recycled materials	1	3
RR10	Educate customers/users about the processes used to recycle	1	2
RR11	Educate customers/users about the options that are available for circular economy, and the performance implications	1	15
RR12	Educate customers/users about how to recycle their products, and how recycling is performed	3	9
RR13	Innovate within the transportation system, e.g., electrification of fleets	2	6
N/A	Others	21	N/A

CE Pathways identified by individual priority ranking scores were then compared to the top three CE Pathways selected via consensus by each group, revealing specific areas of alignment, as indicated by bold CE Pathway IDs in Table 6. This alignment underscores the potential of the collaborative approach to assist stakeholders in making informed decisions regarding the priority areas for a sustainable transition to circularity.

Table 6. Comparative Strategic Priorities, as Identified by Individuals and by Group Consensus

Value-chain stakeholder groups	**Strategic Priorities**				
	Group			**Individuals**	
Chemical Suppliers	**SM5**	**SM2**	SM9	SM1	**SM2**
Manufacturers	M3	**M4**	**M5**	**M4**	**M5**
Recovery/ Recycling	**RR7**	RR5	**RR1**	RR4	**RR1**

For PU foam manufacturers, there is clear alignment at individual and group levels of the CE Pathway priority to coordinate with suppliers to establish clear circular material specifications/requirements (M4), and to simplify material formulations to facilitate end-of-use and end-of-life management and recycling (M5). In the Chemical Supplier's category, individuals and groups agree that the CE Pathway priorities involve collaborating downstream to clarify material specifications and explore alternative applications for recycled content (SM2) and pursuing innovation in feedstock sourcing and material development (SM5). The data also reveals that the group discussion led to a shift: Where individual participants had prioritized collaborating upstream with recyclers to improve material collection and diversion for recycled materials' needs and applications (SM1), group consensus preferred the CE Pathway of collaboration with research teams and institutions investigating chemical recycling potential (SM9) as a more effective to achieve CE. This change in perspective suggests that the academic workshop participants were able to explain their role in developing new ideas and thereby convince stakeholders that collaboration among suppliers and chemical suppliers could be more beneficial.

When tasked to assign desired timelines to each of the identified CE Pathway priorities, a clear sense of urgency and preference for short-term action and progress was evident, with 48% of CE Pathway priorities categorized as short-term goals to be realized in one to five years. These short-term CE Pathways/goals typically involved modifications to the design, production, or consumption of goods and services to reduce waste and promote reuse. In the mid-term timeframe, 35% of the CE Pathway priorities were identified as needing to be accomplished within five-to-ten years. Only 17% of the CE Pathway priorities were listed as long-term (more than 10 year) initiatives, with discussion often reflecting agreement that (paraphrased) "*...we can't wait that long!*".

Timeline dedication to the CE Pathways was the last activity in the workshop that helped participants as stakeholders to classify them to make the transition easier to happen within this industry. According to the data, following discussions within diverse groups, 48% of prioritized themes across various value-chain categories have been categorized as short-term goals (less than 5 years). Additionally, stakeholders have reached a consensus that 35% of prioritized themes can be achieved in the mid-term (between 5 and 10 years), while only 17% of priorities are long-term (more than 10 years) objectives required for a smooth transition to a circular economy. These mid-term objectives were CE Pathways anticipated to require greater investment and collaboration among value chain stakeholders, whereas the long-term CE Pathway priorities were those that were expected to require significant changes to infrastructure, policies, and societal norms to achieve a fully circular economy.

Despite the dedicated attention to establishing timelines for the CE pathways, it became evident that there was some uncertainty among stakeholders regarding the precise duration required for the realization of specific pathways. This underscores stakeholders' awareness of the importance and need for CE Pathways and commitments; however, there was uncertainty about the implementation and research timelines. For instance, when considering most of the groups (4 out of 6) identified the Manufacturer priority to coordinate with suppliers to establish clear circular material specifications/requirements (M4) as a short-term priority; In contrast, there was a lack of consensus regarding an appropriate timeline for the Chemical Supplier priority to collaborate downstream (with manufacturers) to clarify material specifications and explore alternative applications for materials containing recycled–content (SM2). Two groups viewed it as a short-term priority, two as a mid-term priority, and another two perceived it as more suitable for long-term implementation. This may reflect personal knowledge and/or experience collaborating and interacting with Chemical Supplier value chain stakeholders, or it may reflect awareness that the PU foam industry is but one customer of the Chemical Supplier stakeholders, and thus such an initiative is more complex.

4. DISCUSSION

The integration of CE principles into industrial activities is imperative to address environmental impacts, particularly in terms of plastic consumption and waste. This study focused on the polyurethane (PU) foam industry's potential transition to a circular model, employing a collaborative, participatory backcasting methodology. Through the application of backcasting, facilitated structured discussions among PU foam value-chain stakeholders fostered an improved comprehension of the challenges, opportunities, limitations, and innovative domains for CE transition across the PU foam industry.

While conventional narrative often suggests lack of alignment across the value chain, this methodology revealed critical, short-term, and aligned priorities for PU foam industry members. Effectively, representatives from different sectors within the PU foam industry engaged and collaborated in the participatory event that help them to develop a shared vision and enhance awareness about potential opportunities for sustainable transition and CE implementation. Additionally, the collaborative process resulted in the identification of numerous diverse strategic CE Pathways priorities, which can be used to inform the development of a coherent framework for transitioning to a CE. This work provides valuable insights into potential trajectories for the transition to a CE within the PU foam industry and demonstrates the potential of backcasting as a facilitative tool for voluntary industry sustainability initiatives.

From this study, a comprehensive white paper reflecting the co-created set of CE priorities specific to the PU foam industry will be developed and widely shared with industry members and workshop participants for iterative refinement. With additional input and coordination with industry members, the outcomes of this work will be integrated into a strategic CE transition roadmap for the PU foam industry. Subsequent ranking of CE Pathways, first by individuals and then by diverse group consensus, revealed emergent and co-created strategic priorities for PU foam industry circularity, predominately in the short-term (within 5 years). The collaborative backcasting process facilitated a shared vision for CE implementation within the PU foam industry. However, uncertainty remains regarding specific timelines for pathway realization, indicative of stakeholders' awareness of the importance of CE pathways but uncertainty about their implementation timeline.

In conclusion, this study demonstrated the utility of backcasting in driving voluntary industry initiatives in pursuit of sustainability. The resulting CE Pathways offer a strategic framework for the PU foam industry's transition to circularity, guiding future policies and strategies. By addressing technological, infrastructural, and collaborative challenges, this sector can contribute to a more environmentally responsible and efficient economy. This work continues through on-going engagement and assessment activities that include but are not limited to: (a) widespread industry consultation and workshopping to refine the strategic roadmap and develop a corresponding Action Plan; (b) collaboration with the representative industry association, responsible for centralizing and coordinating action – in this case, to adopt the strategic roadmap and action plan; and (c) to request of our industry stakeholders (formally engaged in the broader research project) to adopt and formalize their commitment to the recommended initiatives.

5. RECOMMENDATION

Moving forward, several promising avenues of exploration emerge from this research, paving the way for a more comprehensive understanding of the transition to sustainability in the polyurethane foam industry. The identified CE Pathways provide a foundation upon which further investigations and practical implementations can be built. As an initial step, the research team recommends conducting high-level feasibility studies for the CE Pathways identified as mid- and long-term priorities. These studies can delve into technical, economic, and environmental aspects to assess the viability of each CE Pathway, and guide decision-making. As a more coherent and clarified strategy roadmap for a CE transition is developed, it is recommended that a robust monitoring and evaluation framework also be developed to track the progress of the implemented initiatives, particularly where multiple value chain stakeholder groups are involved and/or affected. Regular assessments can identify successes, challenges, and areas requiring adjustment, ensuring that the transition. Engagement and assessment activities going forward should include, but are not limited to: (a) widespread industry consultation and workshopping to refine the strategic roadmap and develop a corresponding Action Plan; (b) collaboration with the representative industry association, responsible for centralizing and coordinating action – in this case, to adopt the strategic roadmap and action plan; and (c) to request of our industry stakeholders (formally engaged in the broader research project) to adopt and formalize their commitment to the recommended initiatives.

The collaborative and holistic approach taken in this study lays a strong foundation for the industry's sustainable transformation, and these future endeavors may contribute to shaping a more environmentally conscious and resilient industry landscape.

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AUTHOR CONTRIBUTIONS

Mona Abadian: Methodology, data collection, analysing, coding, synthesing, writing and editing.

Jennifer Russell: Conceptualisation, methodology, data collection, reviewing and editing.

DECLARATIONS

Competing interests The authors declare no competing interests.

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APPENDIX

Table A1. Barriers to a Circular Economy Transition for the PU Foam Industry, as Identified by Workshop Participants. Note: List of Identified Barriers Reflects the Verbatim Contributions From Participants; These Were Reviewed and Categorized by the Research Team

Identified barriers	
1	General perception that recycling is not working
2	Affordable scalable depolymerization systems
3	Variability in feedstock
4	Inconsistency of raw material
5	Energy input to recycle/reuse
6	Physical property loss as a product is recycled
7	lack of sustainable economic solution
8	collection
9	lower tolerance for recycled materials
10	Heterogeneous freestreams impact the recycled material quality.
11	often designed for durability/longevity, which is at odds with "easy to recycle"
12	Hauling
13	Transportation (Sheer volume)
14	lack of control over recycling process
15	highly differentiated materials: difficult to get large volumes of the similar materials together for an economically viable recycling process obtaining good reusable products
16	False report about recycling '
17	lack of connections between wastes and recycler companies
18	supply chain constrains
19	economic viability of circular possibility
20	storage
21	non- design for reuse
22	existing manufacturing pathways incompatible with emerging sustainable practices
23	weight
24	green washing has made real improvements harder to market
25	types of products
26	end market development
27	crosslinked materials are often more difficult to convert to useful material
28	impacts beyond circular scop
29	profit
30	reclamation of materials
31	who is recycling
32	regulation on banned substances in certain product formulation
33	dark color of recycled polyols
34	collection
35	lack of incentives to recycles
36	consumer willingness to directly choose to pay for it
37	difficult to effectively describe in marketing for things other than full (or significant) replacement

38	economics
39	lack of technology options for chemical or polymer recycling
40	collection, sortation and transportation of PU ate the end of life
41	value chain alignment on value of recovered polymers Vs. virgin material production
42	collection and deconstruction on complex composition products
43	logistics
44	discard materials are low in economic value so limited incentive to recover
45	separation foam dissimilar material at the end of life
46	catalyst/ additives affecting depolymerization
47	long lived products were made differently 20- 40 years ago
48	product disassembly
49	collection, sorting cleaning of waste streams
50	failure of some chemical process to return the exact starting materials for PU
51	loss of foam properties when the recycled material is used
52	regulatory inconsistency
53	complexity in product mix/waste streams
54	legacy chemicals
55	fear of politicalizing the initiative
56	raw material availability of feedstocks
57	lack of recycling location and process
58	change in material properties
59	concerns for the purification necessary to recover depolymerization products of sufficient purity
60	lack of nationwide primary and secondary recycling infrastructure
61	adhesives
62	poor demand for recovered materials
63	properties of recycled materials are not as good as virgin materials
64	separation out products
65	recycling technics
66	reserve supply chain market channel development
67	concerns of a low energy process that are possible
68	financing mechanisms that are robust through economic cycles
69	integration into existing infrastructure and solution
70	consumers mindset Vs, durability of products
71	proprietary formulations that inhibit recycling
72	land us issues with biomass feedstocks
73	obtaining recycled materials having the same properties or good enough properties as virgin materials
74	lifetime use of the products
75	No outlet established for quantity of recycled materials. Example, a major portion of recycled glass goes to the landfill
76	Plethora of additives & FR's, etc., difficult to identify / detect, so this aspect is not a basis for sorting and can confound molecular recycling processes driving up costs
77	lack of connectivity along value chains particularly at EOL
78	standards and data for life cycle analysis
79	debinding of layers not standardized

80	thermoset nature of PU makes it challenging break down back to raw material for recycling
81	separation of various raw materials presents in the PU foam during recycling
82	consumer base not sufficiently requesting PUF to be sustainable
83	insufficient investment in technology/chemistry to overcome 50 years of innovation to make PUF last forever
84	thinking that durable products don't contribute as much as to the plastic problem as single use products

Table A2. Definition of CE Requirements for Chemical Suppliers Collaboratively Developed by Workshop Participants. Corresponding CE Pathways Were Developed by the Research Team by Inductively Categorizing CE Requirements and Themes.

Identified CE Requirements for Chemical Suppliers to the PU foam industry	
1	Collaborate and coordinate with upstream (recycling activities) actors (e.g., municipalities) to inform disassembly processes that generate their inputs.
2	Product labelling to include composition details that are critical for EOU/EOL management options
3	Engage in landfill mining as new source of material inputs to established recycling systems relevant to PUF
4	Distributed infrastructure for recycling facilities to reduce transportation distance requirements
5	Connection and coordination with recycling actors (providing the recycled feedstock/inputs)
6	Coordinate with other system actors to strategize for achievement of faster economies-of-scale
7	Industry-wide collaborations focused on system-level waste reduction
8	Suppliers to shift into 'recycling' and 'refining' value-added activities to stay connected to the value-chain
9	Collaboration to determine material/substance specifications
10	New opportunities/suppliers to provide inputs to PU Foam manufacturers
11	Explore material/substance/product design options for non-recycling circularity (e.g., remanufacturing, reuse).
12	Education and communication about how manufacturers must adjust to regenerated materials/substances - e.g., not drop-in, so what adjustment is needed
13	Consider alternative industry/product uses - e.g., may not be usable to manufacture original product, but could be cycled into alternative/new applications
14	Coordinate with manufactures to establish higher levels of certainty (e.g., demand stability) to allow for transition time and adjustment
15	Explore potential interconnections between PUF industry and other industries for which there are material/substance overlaps/mutuality
16	Collaboration with upstream suppliers to ensure material specification alignment
17	Explore new business models for raw materials/substances/chemicals that ensure viable financial systems within circular economy
18	Adjust marketing communications to clarify actual differences in circular products/materials, and what those differences mean - e.g., just a color change vs. a performance change (vs. 100% new)
19	Explore business model innovation that is possible for different stages of the production process, e.g., alternatives to buy-sell model
20	Advocate for global alignment of regulatory protocols related to circularity and sustainability
21	How to manage and deal with legacy, non-circular non-sustainable products/materials
22	Establish beyond-PUF material and product flow systems to allow for alternative circular economy applications, e.g., beyond PUF industry
23	Develop national standards for best practice in material, product recycling
24	Consistent incoming stream of materials
25	Long term planning to manage anticipated cost/pricing changes resulting from circularity
26	Financial solutions to manage short-term high prices

27	Normalization of expected circularity in order to motivate supplier investment
28	Clarify the limitations of chemical recycling/molecular recycling possibilities
29	Advance secondary refining activities to increase options for recycled-content applications
30	Invest in development and expansion of bio-based feedstock production
31	Exploration of opportunities presented by new materials having different performance, e.g., new applications possible, new value-chain/supply chains actors may emerge
32	Design of material to enable isolation of the different materials down to the same level used in the initial formulation
33	Support legislative efforts to use greener feedstocks and supply them
34	Diversification of feedstocks across petrochemical and bio-based sources and uses
35	Develop degradable materials
36	Design for material efficiency / material use reduction
37	Advance and normalize use of bio-based and renewable materials
38	Invest in conversion of pre-consumer wastes/scraps into feedstock inputs
39	Establish criteria for recycled content certificates
40	Provide certificates for recycled content
41	Ensure that recycled feedstock have consistent properties
42	Adjust marketing messages to establish and clarify circularity as the standard
43	Establish secondary refining operations (of recycled inputs) to meet evolving specifications and application opportunities
44	Recycled products that can provide the required application properties
45	Exploration of alternative possibilities for substances/materials that are considered harmful / not wanted
46	Evaluate and explore options for obsolete chemicals
47	Exploration of options available for obsolete chemicals
48	Collaborate with depolymerization research and practice to ensure no residual chemicals incorporated into the recycled feedstocks
49	For obsolete chemicals, break-down to atomic level for reuse in different industries
50	Adopt low-energy consuming bio-renewable raw materials as inputs to production
51	Design for ease of recycling at EOL
52	Technology to make consistent products
53	Design products so that required recycling processes are low-impact/mild
54	Convert facilities to low energy / renewable energy
55	Convert plants to low energy
56	Explore alternative revenue-management options, such as extended ROI periods
57	Invest in development of green chemistry practices and reduction of harmful substances
58	Explore options to reduce materials - e.g., single material inputs and/or nanomaterials
59	Distribution of financial support (recycling revenues) to all members of the value chain -cannot be revenue just for downstream parties
60	Advocate for taxes on petrochemically-derived inputs in order to assist with cost-balancing for recycled materials
61	R&D to develop new technology, materials, and product innovation
62	Explore methods to motivate suppliers to invest and transition in the absence of regulation
63	Engagement to ensure that suppliers are not made obsolete because of sourcing shift to recyclers. -- business model innovation?

Table A3. Definition of CE Requirements for PU Foam Manufacturers Collaboratively Developed by Workshop Participants. Corresponding CE Pathways Were Developed by the Research Team by Inductively Categorizing CE Requirements and Themes.

Identified CE Requirements for PU foam manufacturers	
1	Establish Mfg. in-house options/facilities to reuse waste or finished goods
2	Establish local recycling of pre-consumer scrap (in-house streams) to avoid downgrade to rebound-only options
3	Closed-loop pre-consumer (industrial) systems: PU scraps are captured and cycled back into the feedstock system in-house
4	Manufacturing wastes are captured and cycled back into the production process
5	Design product to ensure that customer expectations of performance are part of the original specifications, including verification of use of reclaimed materials.
6	Engage with relevant supply chain partners to discuss and establish circular material specifications
7	Educate consumer about why performance of circular product may be different, e.g., due to next-life design requirements
8	Establish and communicate the recyclability of the product (e.g., how to recycle)
9	Invest in digital passport evolution, including tracking of materials and components
10	Provide verification/tracking of material sourcing and circularity
11	Digital composition traceability (e.g., digital passport dataset) to inform EOU/EOL processing
12	Establish and provide a certificate of recycled content
13	Use of "Nutrition Label" of product to describe life span
14	Products manufactured with labels, identifiers, instructions to make separation and management at EOU easier
15	Identify material components on product to ease recycling
16	Add physical and chemical labels for identification and sorting into category groups for recycling
17	Coordinate manufacturer and supplier requirements/specifications to ensure that reformulated new materials are aligned with product/application design requirements
18	Establish clear material specifications to ensure equivalent products from multiple suppliers.
19	Coordinate with chemical suppliers to enable changes in basic formulations needed for circularity, in advance of product design and manufacturing
20	Reduce the number of grades (e.g., only 5 grades of PU Foam) that can be used/introduced into a product
21	Simplify material formulation to make recycling easier, lower cost, and improve secondary market for recycles.
22	Design product in a way that enables easier material-level recycling
23	Use additives that act to breakdown the materials after a specific time frame
24	Design to degrade: Addition (catalyst/enzyme) that can be triggered to being degradation at a specific point in time
25	design additives/flame retardants to be more easily separated/removed during the recycling process
26	Fabrication/assembly done in a manner that enables disassembly to pure material streams
27	Design for circularity: new product development must consider EOL options that ensure circularity
28	Design product for disassembly and recycling; separability of components (e.g., coils) vs. materials (e.g., foam)
29	Ensure balance between durability of material and circularity as two viable circularity options
30	Design for disassembly cannot affect product performance. Disassembly must be controllable.
31	Design products that use circular materials with newly defined specifications (circular product development)
32	Design products that use circular materials with newly defined specifications (circular product development)

33	Design products that are made for circularity
34	Figure out how to refine EOL materials so that they are suitable for inputs to foaming process
35	Explore secondary refining step to take recovered materials and customize them to be appropriate for the specifically desired application.
36	Establish industries for purification of consumer waste to ensure purity of new feedstock for manufacturing
37	Design/implement modular setups for chemical recycling
38	New suppliers/sources for feedstock from circular options (e.g., recycled inputs) -- explore/expand sourcing to include new players.
39	Emerging upstream suppliers and products should be considered during product development - grow the ecosystem
40	Establish clear supply chain of feedstocks of clean monomers from recycled sources
41	Communicate with consumers/customers to manage expectations about performance of the circular product (if different from the convention). Both value and risk.
42	Collaborate with EOU/EOL partners to streamline and improve the efficiency of take-back - e.g., decentralized responsibilities and systems
43	Collaboration and coordination and partnerships across supply chains to enable collective environmental impact reductions
44	Recycled materials fully compatible with manufacturing systems and equipment
45	Ensure that harmful chemicals from depolymerization process are fully removed from the recycled feedstocks generated by that process
46	Manufacturers provide the collection system for EOU products
47	Manufacturers provide local recycling centers for their customers
48	Collaborate to establish designated recycling industries for PU Foams
49	Transportation system innovation (forward and reverse-logistics) to ease cost and environmental impacts of moving products
50	Post-industrial waste is captured as pure PU waste stream, depolymerized into starting monomers, and then reused
51	Collected waste can be easily incorporated into new products
52	Develop green blowing agents that are non-hazardous
53	Plants are electrified and renewable resources are utilized as much as possible
54	Leadership on industry collaboration to find alignment across diverse interests, priorities, and material/product design strategies
55	Develop different kinds of circular pathways for different types of PU Foam (e.g., rigid vs. flexible; by application)
56	Allow time for economies of scale to be realized for new circular materials, e.g., to become more cost-competitive requires investment and development
57	Exploration of renewable materials/polyols
58	Advocate for regulations/laws that also provide incentives/funding to support transition to greener materials and recycling of materials
59	Clarify differentiation of organization (vs. competitors) when all materials are circular
60	Depolymerized monomers can be used at all re-incorporation levels without affecting desired properties
61	Costs for recycled materials are same or lower than primary materials
62	Segregating foams earlier in the recovery process

Table A4. Definition of Ce Requirements for PU Foam Recovery and Recycling Stakeholders Collaboratively Developed by Workshop Participants. Corresponding CE Pathways Were Developed by the Research Team by Inductively Categorizing CE Requirements and Themes.

Identified CE Requirements for recovery and recycling stakeholders in the PU foam industry	
1	Explore/establish byproduct markets, e.g., urea
2	make the circular economy for the additives which are used in the production process
3	find the customers for using the recovered materials
4	mechanically recycled material can be functionalized to use in the other industries
5	Design recovery system to ensure most pure streams for recycling
6	Establish clear, efficiency, collection systems and streams to enable more pure inputs to recycling processes
7	need a collection infrastructure to keep materials clean and dry
8	Partnerships with large-scale consumers like hotels/universities so they can get solid waste streams that are consistent
9	Legislature - tax incentives for hotels or bi consumers of mattresses to cooperate with recycling companies for recovery of the material
10	identify ways and methods to eliminate any "unsuitable" materials
11	the material which is come out of recycling should be free from contamination
12	develop different dedicated streams and collection paths for a variety of end-use products
13	Create incentives for consumers to recycle or return used mattresses to collection centers for ease of collection
14	collaborate with retailers and other organizations (except the government) to run the events, to manage the collections and make infrastructure
15	Start a company that can pick-up large, manufactured products for recycling
16	manage to remove the unsuitable returned product such they are wet or has bed bugs
17	pre transport procedures (shredding, compression)
18	Establish industry/companies dedicated to disassembling specific PUF products (similar to automotive scrap system)
19	cooperate with logistic companies to transport the PUF based product to a facility equipped to dismantle
20	redistribute the products recovered to facilities that can further process
21	have or make the disposal and dismantling location nearer (less than 300 miles or less than 150 miles)
22	localized recovery to minimize the transportation
23	to reduce the foam volume (crushing, shredding or palletizing) to reduce transport cost and handling
24	Invest in non-reductionist recycling processes (high-tech; chemicals)
25	Invest in non-reductionist recycling processes (high-tech; chemicals)
26	Need a list of materials/composition to allow for easy disassembly and sorting
27	engage communities to do recovery efforts
28	to map the collection infrastructure based on the final products
29	collection infrastructure needs to be connected to recycling
30	Clarify (for users) the structure of the recycled polyol (output feedstocks)
31	educate people to use them by end of product life
32	clarify the second use for products
33	increase pressure to social and norms to recycle
34	consumer education for proper recycling

35	Design a recycling process which is easy and convenient for consumers and manufactures
36	drivers' availability to recover materials Vs. other industries, volatility of drivers will cost
37	define economical waste transport
38	Minimal impact manufacturing
39	Advocate for landfill bans for PUFs (once recovery systems are established)
40	Set goals/targets of 100% recycling via combined mechanical and chemical recycling
41	Standards and assurance of biosafety and worker safety standards for recycling actors
42	subsidies and/or cost parity with virgin feedstock
43	lower fuel price
44	incentivize from the supply chain from the consumer returns to raw material
45	national training and engagement to show the value and need for circularity
46	develop some circular material which could be substituted by some of the flammable agent =s in foam products
47	make simple formulation, since the integration of various components will complicate separation process
48	create Parity with virgin stock
49	make PU products (such as insulation) should change to particles that can be easily separated, collected and reused at EOL in new products
50	need incentives to get the foam out of every end-use product instead of being throwaway
51	Simplify materials used and product design to enable easier EOL disassembly
52	clear identification of all raw material component streams
53	Research to explore the low energy depolymerization/chemical recycling process
54	Research to address color changes in materials that may result from chemical recycling/depolymerization
55	Research to consider how to overcome the viscosity change that may result from chemical recycling / depolymerization
56	Research to clarify the impact of depolymerization catalysts upon the structures of the output material (material that has been recycled)
57	Research to assure comparable structure relationship and morphology, and performance
58	Research to isolate and recover isocyanates
59	Research to recovery primary amines as part of the process; these can also be used as recycled feedstocks