Chapter 6
Circular Economy and New Research Directions in Sustainability

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6.1 Introduction

6.1.1 Circular Economy and Sustainability

Circular economy presents a new practical approach to sustainable development. Circular economy refers to redesigning, reusing, recycling, remanufacturing, or redistributing waste products, or prolonging product life through maintenance, to increase the added value of products by different circular setups. This new development pattern is beneficial to boosting economic development, facilitating resource efficiency, and reducing environmental pollution. Hence, many countries such as EU countries have taken circular economy as a pathway to sustainability, and have further formulated targets and measures for circular economy. In addition to environmental and economic benefits, circular economy can also support job creation, counteracting social problems arising from unemployment, and promoting social sustainability. Circular economy has a strong potential to transform the society toward environmental, economic, and social sustainability.

In 2000, the United Nations (UN) proposed 8 Millennium Development Goals (MDGs) in the Millennium Summit, and the 189 UN member countries undertook to pursue the 8 MDGs. When the MDGs were due in 2015, only preliminary progress had been made and the world was still confronted with the challenges from climate change and other environmental issues. In the Earth Summit held in Rio de Janeiro (Rio20+) in 2012, the UN placed more emphasis on the impacts of climate change, as well as planetary boundaries and social equality. Eventually, the member countries resolved to use 17 Sustainable Development Goals (SDGs) as the critical directions to address sustainable development from 2016 to 2030. The 17 SDGs

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comprise 169 sub-goals. Among the sub-goals, SDG 12 (Responsible Consumption and Production) is closely associated with circular economy, because circular economy serves to improve resource efficiency, slows down the exploitation and consumption of resources, and thus accomplishes sustainable production and consumption. In addition, the development of circular economy has directly resulted in the progress of several SDGs globally, including SDGs 6, 7, 8, 11, 12, 14, and 15 (Schroeder et al. 2018). SDG6 (Clean Water and Sanitation) mainly focuses on sustainable management of water and sanitation. SDG7 (Affordable and Clean Energy) mainly focuses on access to energy sources, microbial anaerobic digestion, and utilization of methane gas generated by anaerobic digestion; SDG7 is highly promising in terms of the utilization of agricultural wastes. SDG8 (Decent Work and Economic Growth) is to build a sound and productive employment environment through economic growth. SDG11 (Sustainable Cities and Communities) focuses on the tolerance, security, resilience, and sustainability of cities and communities. SDG12 (Responsible Consumption and Production) is to ensure sustainable consumption and production. SDG14 (Life below Water) focuses on conservation and sustainable utilization of oceans and marine resources. SDG15 (Life on Land) is to protect, maintain, and promote sustainable use of terrestrial ecosystems, manage forest resources, combat desertification, stop and reverse land degradation, and prohibit the loss of biodiversity. Table 6.1 lists the actions that could be taken by circular economy to attain the SDGs, and the influence of such actions.

6.1.2 Concepts and Principles of Circular Economy

For a long time, mainstream economic development has been based on the linear economy pattern. In an industrial production and consumption system, the exploitation, manufacture, use, and scrapping of resources follow a linear mode across the whole process from cradle to grave. Under the linear economy pattern, many resources are used only once, thus losing their utility and value. In contrast, "circular economy" highlights optimized use and consumption of natural resources, or to be specific, innovates the traditional production-supply pattern and creates a new consumption pattern. Rather than waste reduction in a traditional sense, circular economy places more emphasis on innovative design in new aspects (including technological, organizational, and social innovation), so as to affect the value chain of an economic system (EC 2014). The ultimate goal of circular economy is to decouple global resource consumption and environmental impact from economic development.

By assimilating related concepts and principles, such as industrial ecology, cradle to cradle, and performance economy, circular economy changes the economic logic, create alternative routes of materials, and becomes an important and practical mechanism to pursue sustainable development goals (Saavedra et al. 2018; Kirchherr et al. 2017). Industrial ecology is concerned with the material and energy flows through the industrial system and the associated impact, and provides a holistic

Table 6.1 Actions by circular economy and their association with the SDGs (Schroeder et al. 2018)

SDG 6 Clean Water and Sanitation Development of water recycling technology, reduction in irrigation water by precision agriculture, pipeline leak detection by smart water meter, monitoring the change in water quality, and tracking pollution sources by Internet of Things (IoT)
SDG 7 Affordable and Clean Energy Incinerators as energy recycling centers, agricultural wastes as bioenergy, transforming organic matter into methane gas by wastewater treatment plants, encouraging use of renewable energy
SDG 8 Decent Work and Economic Growth New employment opportunities and economic growth impetus are sourced from the following factors: business models of product servitization, circular logistics systems, circle-oriented product and manufacturing process design, associated network service development, R&D of recycling technology, marketing, and quality inspection and certification.
SDG 11 Sustainable Cities and Communities Circular cities, sharing cities, effective material sorting and collection facilities, reuse markets, urban mines, and roof and park-style farmlands
SDG 12 Responsible Consumption and Production Extended producer responsibility (EPR) in recycling, recyclable design, naturally decomposable material design, integration of arterial and venous industries, reduction in the use of nonrecyclable materials, reduction in industrial wastes and pollution, reduction in carbon footprints and water footprints in manufacturing processes, and integration and reuse of energy and resources by industrial symbiosis
SDG 14 Life below Water Reducing and removing marine plastics, and reducing seawater eutrophication caused by nitrogen and phosphorus nutrients
SDG 15 Life on Land The improvement in resource efficiency brings about reduction in forest exploitation, mine exploitation and related pollution, wetland exploitation, and soil loss and soil degradation arising from intensive agriculture.

framework for guiding the transformation of the industrial system to a sustainable basis. The central goal of IE is to move from a linear to a closed-loop production and consumption system (Lowe and Evans 1995). The cradle-to-cradle looks at the life cycle of a product or a system and looks for optimal ways of closing the loop of materials. With emphasis on the design phase, it serves a measurable form of circular economy at the product level and provides a detailed list of practices to navigate through higher levels of circularity for sustainable development (Ünal and Shao 2019). The performance economy represents a full shift to servitization, with revenue obtained from providing services rather than selling goods. Key elements of the performance economy are reuse and remanufacturing as well as innovative business models, to maintain the quality of stock and extend its service life by reducing material intensity (Stahel and Clift 2016).

The Ellen MacArthur Foundation (EMF), a British organization committed to promoting circular economy, formulates three principles for circular economy: (1) preserve and enhance natural capital by controlling finite stocks and balancing natural resource flows; namely, if resources are needed, the circular system can choose technologies or processes involving recycled or better resources; (2) promote the recycling of products, parts, and materials through the technical or biological cycle, to maximize utility and improve resource benefits; and (3) boost system efficacy, and reveal and remove externalities with negative impacts; namely, reduce the loss of the circular system and manage the related external factors (EMF 2015a). The characteristics of circular economy include zero waste design, stability of the circular system by diverse circular paths, use of renewable energy, systems thinking, and prices and other mechanisms that reflect real costs. Circular economy advocates that resources should maintain their highest value; resources should be used continuously in a more efficient manner. Raw materials, products, and wastes are the forms that resources assume in different stages of their life cycle. EMF (2012) proposes four principles (as shown in Table 6.2), to specify the stages in which businesses can create value and expound the implications of such value to businesses.

As shown in Fig. 6.1, the whole system of material flows comprises two circular subsystems, including the technical material circular subsystem and biological material circular subsystem. The system is integrated with the original linear economy, namely, throughout the whole life cycle of materials from raw material exploitation and manufacturing, parts manufacturing, product manufacturing, service and product provision, product use and consumption, energy recycling, and waste and landfill. For resource recycling in the traditional sense (3R, including Reduce, Reuse, and Recycle), most materials will be treated in three ways at the end of their life cycle: (1) recycled as raw materials; (2) heat recovery through incinerators; and (3) final landfill. In contrast, circular economy highlights other circulating methods.

For the technical material circular subsystem, the circulating methods to be added include renovation or remanufacturing, reuse or redistribution, and repair. For the innermost circulating method, the value of products or materials can be kept (including the use for its original purposes) through the least processes, namely, with minimized costs and environmental impact. For the biological material circular subsystem, most of the materials can be naturally decomposed and recycled in the environment. For material circulation in the traditional sense, materials return to natural soils, but the potential utilization value for materials would be nearly lost. The lower part of Fig. 6.1 shows other valuable circulating methods for biological

Table 6.2 Four principles for value creation (EMF 2012)

	Principles for value creation	Description
1	The power of the inner circle	A circulating path as short and compact as possible is beneficial for retaining the maximum product (resource) value and creating service value.
2	The power of circling longer	It is advisable to extend the duration and times of circulating, thus saving the energy and resources required for manufacturing new products or parts and creating service value.
3	The power of cascaded use	Waste can be reused across different industries, thus accomplishing industrial symbiosis and creating new value for resources.
4	The power of pure input	In the manufacturing process, nontoxic materials should be used, and composite materials should be avoided. Clean and simple raw materials are beneficial for retaining resource value.

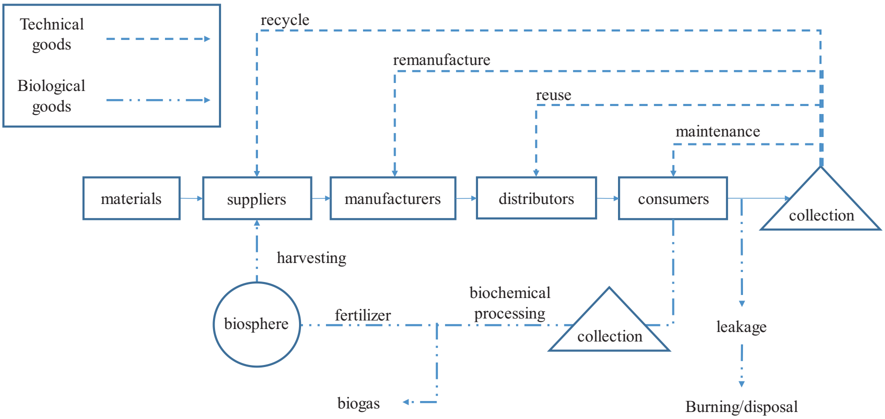


Fig. 6.1 A material flow model of circular economy. (Adapted from EMF 2012)

materials. Multilevel cascaded circulating methods can be developed. Some biological waste materials contain constituents with functional biochemical properties, so valuable biochemical materials could be extracted from them.

6.2 Literature Review

6.2.1 Goals and Strategies for Developing Circular Economy

According to the goals of circular economy set from top-down, many countries develop strategies that drive the transition of market operation to circular economy. The related goals and strategies on circular economy can be described in three aspects: target setting, governmental strategy, and market operation.

6.2.1.1 Target Setting

The management strategies related to circular economy have evolved through several stages, including waste management in the early stage, subsequent focus on sustainable material management, and the consummating circular economy in the recent stage. By extending the early goals of waste management to pursue maximization of the resource values of the overall system, many countries try to strengthen waste management with the purpose of increasing resource productivity. The goals have been expanded to consider their consistency with sustainability, and the strategies are designed to address the life cycle of products and materials.

Many countries have upgraded their waste management targets. Specifically, they not only reduce waste generation, but also restrict landfills of waste. The EU set its waste reduction target for landfills at 10% (EC 2015). Japan plans to reduce their waste generation to 25% of that in 2000 by 2020 (Ministry of the Environment (Japan) 2017). Denmark is working to reduce 15% waste amount by 2030 (ABCE 2017). France plans to reduce their wastes to 50% of those in 2010 by 2025 (French Ministry of the Environment 2018).

In accordance with the waste reduction targets, these countries strive continuously to attain their recycling targets. The EU Closing the Loop action plan has set recycling targets for 2030, which are 65% for municipal waste and 75% packaging waste. Denmark has set their waste recycling target at 80% (ABCE 2017). Furthermore, certain countries have set recycling targets for specific types of wastes. For example, France has set their plastic waste recycling target as 100% for 2025 (French Ministry of the Environment 2018).

The targets of increasing resource productivity are usually embodied in the improvement of national-level resource productivity or the reduction of raw materials consumption. For example, the short-term targets of China for circular economy include a 15% improvement in resource productivity by 2020 as compared to 2015 (NDRC of the People's Republic of China 2017). The transition targets of Denmark include a 40% improvement in resource productivity by 2030 (ABCE 2017). The use of raw materials is often included in material management targets for many countries. For example, the EU expects to reduce 20% of raw material consumption in the process of food production by 2020, and the Netherlands has set an intermediate target of reducing 50% consumption in mineral, fossil, and metal materials by 2030 (Ministry of Infrastructure and the Environment 2014).

As for circular economy targets, Denmark stood out to set direct targets. By 2035, (1) 75% of Danish industries and the service industry should take an active part in circular economy, to improve the added value by 15%; (2) 50% of the consumer demand should be met by sharing economy; and (3) the revenue from biolabeled products and services should quadruple to promote circular consumption (ABCE 2017). Although many other countries have not set direct targets, they have taken actions to improve product design in durability and recyclability, to foster the maintenance, reuse, and recycling markets, and to increase circular consumption behaviors.

6.2.1.2 Governmental Strategy

To accomplish the targets for circular economy, national-level strategies such as infrastructure reinforcement, industrial investment and taxation are carried out to impel industries to transform themselves toward circular economy. Infrastructure reinforcement involves treatment facilities for resource recycling. For example, UK's infrastructure reinforcement involves the collection, sorting, and repair or retreatment of products and materials, reducing the costs of secondary materials. Infrastructure reinforcement also involves urban or regional construction for behavioral change on the demand side. In China, the government coordinates the overall planning of urban production, citizen living, nature conservation, waste treatment, and green infrastructure reinforcement. To attain the circular economy targets for 2050, India advocates the development of smart cities and industrial corridors, speeding up the construction of urban infrastructure based on the principles for circular economy and preventing enduring inefficient resource systems (EMF 2016a).

Increasing the investment and funds for circular economy is also an important measure taken by many countries and related organizations. In conjunction with the European Commission, the European Investment Bank, and financial market participants and businesses, the EU is building and optimizing a financial support platform for circular economy, to increase the attraction of circular economy projects to investors (EC 2017). The Netherlands is building a turnover capital platform for circular economy (Ministry of Infrastructure and the Environment 2014). Japan has set up the Coordination Funds for Active Environmental Research, to finance research on circular economy and R&D of related technologies and equipment. South Korea attracts private investment by government intervention, by means of green finance products (Jin 2016).

Taxation includes tax levies and breaks. Tax levies are mostly used to facilitate government supervision, whereas tax breaks are used to invigorate market operation. The EU increases levies on landfill and incineration taxes to reduce waste disposal, levies on unrecyclable commodities and products containing toxic substances to reduce their usage, and set tax rates according to the recycling degree of products to promote the reuse of parts of second-hand goods. The Netherlands plans to levy value extracted tax (VET) instead of value added tax (VAT), which levies according to the type and quantity of brand-new raw materials used, and in turn encourages the use of renewable raw materials. In addition, the Netherlands sets differentiated tariffs (DIFTAR) for waste treatment according to the type of waste. The differentiated tariffs mechanism is intended to create incentives for businesses and individuals to reduce the generation of high-rate wastes for the purpose of tax saving. The UK encourages the use of durable and recyclable products and materials by levying tax on raw materials and resources, and landfill taxes as an economic incentive tool to control the quantity of waste disposal.

Government control measures include the following: (1) preventing the generation of waste; (2) reducing the quantity of waste entering landfills; (3) perfecting resource recycling systems; and (4) strengthening the EPR. These are waste management measures often taken by countries.

6.2.1.3 Operation Mechanism of Circular Economy

Among the circular economy policy viewpoints of various countries, it has been found that platform building and procurement strategies serve to strengthen the supply capacity and demand motives. Platform building is beneficial for (1) expanding sources of funding, (2) diversifying material supply, and (3) promoting the exchange and sharing of technical information; it is intended to bolster the supply-side capacity. For example, the EU plans to enhance financial support platforms for circular economy (EC 2017), and the Netherlands has designed a funding turnover platform

(Ministry of Infrastructure and the Environment 2014). Diverse material supply simultaneously includes diverse unused resources (including material sources, machinery, and services) and demands on the same platform. For example, the EU suggests that platforms be built for second-hand goods sale, sharing, and provision of maintenance and repair services. The Netherlands's packaging innovation system will build a packaging center and report platform for interactions between producers and consumers. In addition, the UK's circular economy strategy also suggests that a free information platform be applied to provide small and medium enterprises with the skills and tools for improving material use efficiency; this system will enable small and medium enterprises to know the quantity of waste they generate and the effect of such waste on their profits, as well as provide methods for waste reduction and cost saving (WRAP 2013). The UK also provides a platform to match demanders and suppliers, wherein consumers purchase the right to use rather than the ownership of commodities, namely, substituting purchasing with leasing; compared with the traditional purchase of commodities, this serves to maximize the utilization of commodities and reduce the possibility of disposal. Exchange and sharing of technical information can be seen on the EU platform built for circular economy stakeholder engagement, allowing stakeholders to brainstorm and conceive the objectives and execution contents of the platform; the platform currently presents related cases, dialogs between stakeholders, and related knowledge and strategies (EC 2017). Various communities in the UK also exchange information on resource efficiency through platforms to conduct technical exchange and cooperation. For example, the EMF has set up the Circular Economy 100 (CE100) platform committed to facilitate cooperation between leading businesses, local governments, and advanced technologies; it offers three types of support: (1) building a problem-solving mechanism; (2) establishing a database for optimal operation guides promptly accessible to businesses; and (3) providing a mechanism for businesses to ponder the development of circular economy, in order to speed up the transition.

In another aspect, procurement strategies can strengthen the motives of the supply side to adjust in response to demand. Procurement strategies can be roughly classified into mode and commodity approaches. Mode approaches include sharing economy and product-as-a-service, while commodity approaches imply setting restrictions on commodity properties, such as green-labeled or recyclable. The EU's main strategies include product-service system and green public procurement, and has issued a new green public procurement directive in order to oversee its member countries to fulfill the target of a 50% green public procurement rate, thus promoting the market development of circular economy through the enormous government procurement power. In response to the foresaid procurement choices, there are three schemes for executing product-design requirements in the EU's existing regulations: (1) reinforce the existing Eco-design Directive, and ultimately extend it to non–energy-related products; (2) guide commodity design through the Waste Framework Directive and Packaging and Packaging Waste Directive; and (3) integrate and simplify issues on circular economy through existing technologies and regulations, such as green labeling, green government procurement, eco-design, and energy labeling. The EU needs to establish mechanisms on eco-labeling and green public procurement to further encourage the use of recycled goods, and develop proper certification methods at the same time (EEB 2015). The UK Department for Environment, Food and Rural Affairs promulgates the decree of Government Buying Standards (GBS) to regulate the procurement of various commodities (including furniture, electric and electronic appliances, and transport vehicles) by central government agencies. The GBS considers the circulating concept by design and highlights the reparability, upgradeability, and recyclability of products; it intends to make government agencies play an exemplary role and promote the market development of circular economy through their procurement power.

6.2.2 Business Models for Transition Toward Circular Economy

From the perspective of supply chain management, circular economy promotes the sustainability of supply chains with the creation of self-sustaining production systems from revaluing materials (Genovese et al. 2017; Geissdoerfer et al. 2019). In addition, innovative business models, the key enablers for circular economy, are crucial to the success of business operation, and will contribute greatly to the transition toward green growth as well as strengthen the competitiveness of enterprises and the supply chain (OECD 2019). Existing business models cannot satisfy the requirements of circular economy because most enterprises create economic value based on a linear economy thinking.

EMF (2013) defines the circular business model as an important tool to promote the core concept of circular economy at a micro level, namely, establishing a renewable closed system; the greatest difference from those of linear economy is that the latter lacks the thought of reverse logistics returns products to the manufacturing processes or markets. Many international think tanks, research institutes, and consulting firms, such as Accenture, EMF, Forum for the Future, Circle Economy, and BSI, have proposed various types of business models for circular economy (Pieroni et al. 2019). The classification and presentation by Accenture are clear and lucid; explanations accompanied by the life cycle chart (Fig. 6.2) enable enterprises to contemplate more intuitively strategies and business models applicable to various stages in life cycles. Therefore, many international organizations have adopted Accenture's show-how to describe business models of circular economy.

The typical life cycle includes seven stages: product design and material procurement, manufacturing, logistics, sales and marketing, product use, end of life, and reverse logistics. By analyzing 120 successful commercial cases of successful improvement in resource productivity, Accenture sums up five categories of circular business models: (1) circular supplies: future circularity of the whole system should be considered at the very origin of the life cycle (product design and raw material procurement), to ensure healthy circulation in the whole supply chain; (2) resource recovery: the possibilities of economic value re-creation should be considered of

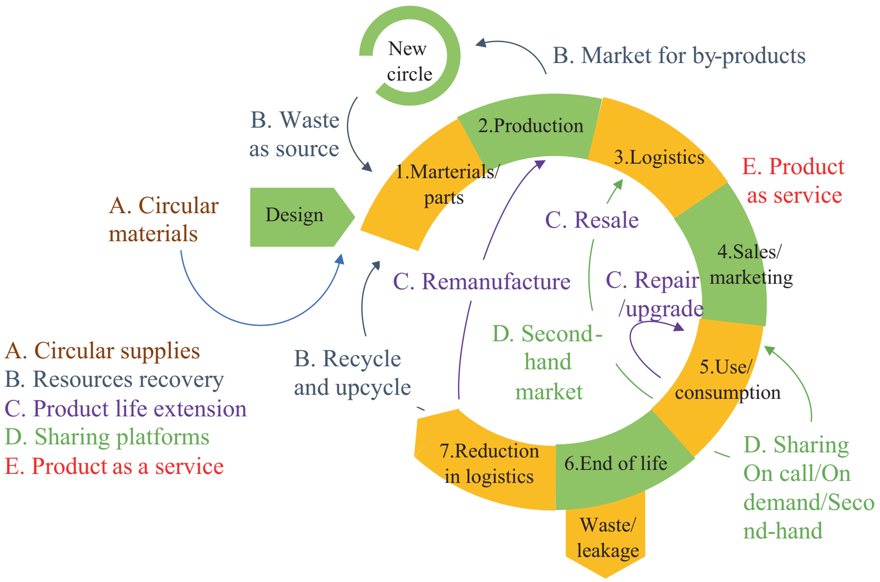


Fig. 6.2 Types of business models for circular economy (Accenture 2014)

residues from manufacturing processes and wastes from final consumption, to return discarded resources into circulation; (3) product life extension: to prolong service life of products through maintenance service, resale, and remanufacturing; (4) sharing platforms: information and transaction platforms for improving utilization rates of various idle assets at the use stage; and (5) product as a service: providing service of using a product rather than selling the product itself through leasing or pay-per-use mechanism. In addition, Accenture emphasizes that popularization of digital, physical, and biological technologies could promote circular economy if properly used.

EMF and McKinsey proposed the ReSOLVE as a strategic architecture for enterprises to develop circular business models (EMF 2013). ReSOLVE stands for Regenerate, Share, Optimize, Loop, Virtualize, and Exchange. The business models proposed by Forum for the Future mainly fall into two categories, one coined “circular” and the other “enabling.” A circular business model aims at improving circularity of the overall commercial system through disruptive innovation as well as feasibility and popularity of product reuse through mechanisms and commercial design, mainly examining business opportunities of reverse logistics through product life cycle; an enabling business model refers to one that serves to promote or reinforce a circular business model. With the Value Hill framework, Circle Economy (2016) explains how to rethink and create value in a circular economy throughout three major stages in terms of product life cycle: (1) creating value, (2) maintaining value, and (3) retaining value.

The British Standard Institute (BSI) released BS 8001:2017 Framework for implementing the principles of the circular economy in organizations—Guide. This document proposed six circular business models, including on-demand production, dematerialization, product life cycle extension/reuse, recovery of secondary raw materials/by-products, product as a service/Product Service System, as well as sharing economy and collaborative consumption (BSI 2017).

6.3 Assessment Tools

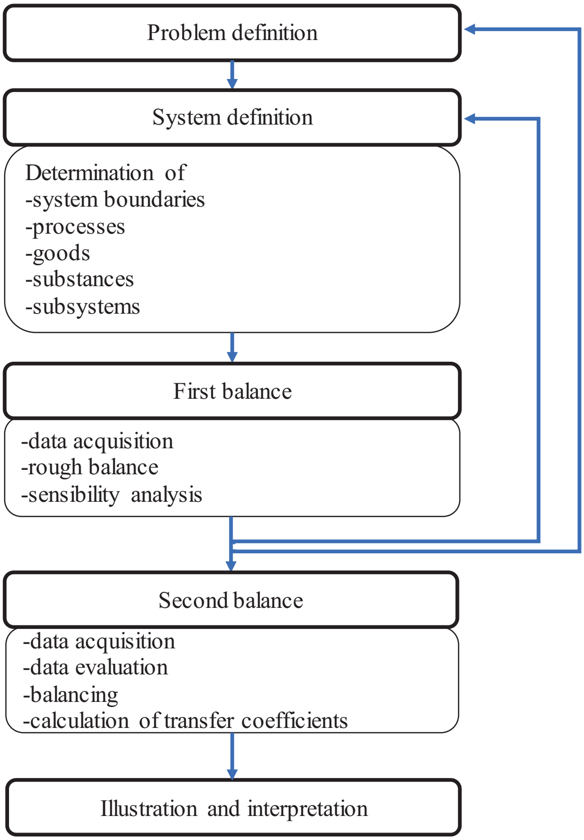
6.3.1 Material Flow Analysis and Related Analytical Approaches

Material flow analysis (MFA) is a systematic assessment method used in environmental management to evaluate the flow and stock of materials within a certain spatiotemporal range (Brunner and Rechberger 2004; Wang and Ma 2018; Lavers et al. 2019). Materials can refer to substances or goods. In chemistry, substances are defined as types of matter that comprise uniform homogeneous units. If such units are atoms, the substances will be referred to as elements (e.g., C and Fe); if such units are molecules, the substances will be referred to as chemical compounds (e.g., CO_2 and $FeCl_2$). Goods refer to valued entities that comprise one or multiple substances. Some materials possess positive value (e.g., automobiles, fuels, and wood), while some possess negative value (e.g., wastes and sludge). A material flow system comprises flow, process, and stock; MFA is primarily based on the law of mass conservation, meaning that within a system, the mass remains unchanged and substances cannot be created or consumed with the lapse of time. Often used as a decision support tool in resource management, waste management, and environmental management, MFA can present complete and consistent information about the sources, pathways, intermediates, as well as final sink of the target substances.

The steps of MFA are shown in Fig. 6.3 (Baccini and Brunner 2012), mainly including problem definition, system definition (determination of system boundaries and selection of substances, goods and processes), determination of flow and stock (measurement of material flows, balancing of goods, inventory and calculation of concentrations, and balancing of substances), and result interpretation. Note that these steps need not be executed continuously in a strict manner, but should be optimized repeatedly so that they can meet the research objectives. Generally speaking, a desired practice is to first estimate data roughly and then improve the system and related data until the data quality meets a certain standard. MFA is an iterative procedure, and the selected components (substances, processes, goods, and boundaries) and exact data need to be repeatedly confirmed with the targets.

The goods and material concentration data for MFA can be empirically measured, and the estimates of this part depend on the available financial resources. For a large system or a long time period, this type of assessment may incur high costs. Therefore, flows, stocks and concentrations are preferably measured within a smaller system, such a waste treatment plant, a company, a farm, or a single

Fig. 6.3 Processes of material flow analysis (Baccini and Brunner 2012)



household. Such research entails an intensive and time-consuming inventory and calculation procedure. Notwithstanding recent studies aimed at improving inventory and measurement methods in MFA, there have been very few systems with balance error between inflow and outflow less than 10% of the total flow.

MFA has become an indispensable tool for research on transition paths toward circular economy at a national, urban, or corporate level. In such applications, MFA performs the following functions:

1. Understanding by inventory overall material flows of the observation objects (e.g., overall national resources, single industry, or company), as well as system status, in order to find out key factors and map out transition paths.
2. Pinpointing key locations of material losses within the target system. Locations with severe material losses are also hotspots that decision makers can aim at to plan and implement appropriate management measures (e.g., optimize manufacturing processes and formulate alternative schemes).
3. Recognizing distinctly sources of resource flows and the units to which the resources belong. This serves to obtain a bird’s eye view of the system, and

connect related departments to maximize reuse rates (e.g., the wastes of one sector may become raw materials of another) and improve circularities of resources.

4. Identifying driving factors of material flow directions, in order to improve the overall utilization of resources starting from the design stage of circular economy.
5. Assessing the current extent of circular utilization of the target system through inventory results which can be used as data source for evaluating circular economy indicators.
6. Supporting evaluation of the economic value of an enterprise's material flows.

In addition to analysis of material flows in the anthroposphere and the environment, the evaluation of the impact derived from the flows is also needed to formulate management strategies. From the product life cycle perspective, input of energy and resources as well as generation of related pollutants at the raw material extraction, product manufacturing, consumption, circular utilization, and final disposal stages are all focal points of follow-up tracking and assessment. Life cycle assessment (LCA) is an objective process to assess the environmental load of products, manufacturing processes, activities or policies throughout the whole life cycle, from cradle to grave; it identifies and evaluates usage of energy and resource as well as emissions to the environment, and assesses in turn opportunities for further environmental improvement (Curran 1996; Haupt and Zschokke 2017; Ingrao et al. 2018). LCA comprises four steps: goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation; as a common method for evaluating environmental performance, LCA is especially suitable for assessing circular business models because circular economy calls for a systematic view (WBCSD 2016).

Cost–benefit analysis is also a common tool for research on circular economy (Lacovidou et al. 2017; Gigli et al. 2019; Huysveld et al. 2019). In a systematic manner, this tool can present the economic, social, and environmental impacts, within a specified time period and in terms of monetized costs and benefits, from the practices advocated by the circular economy concept. The intent is to select the best solution with maximized benefits and minimized costs. However, the disadvantage of this tool lies in the monetization process. It is not easy to convert impacts on various aspects into money as the sole unit of measurement; in addition, the element of time must be considered by incorporating the discounting factor into the monetization process. To promote the development of circular economy on a global scale, it is nevertheless necessary to motivate enterprises and even the whole society to transform from linear economy into circular economy by giving prominence to the higher cost efficiency and sustainability of the latter; it is thus necessary to rely on cost–benefit analysis to present the outlook for circular economy transition in a monetized manner. Like all public policies, governments or enterprises will invest only in projects with costs-beating benefits or minimal costs. In the process of transition toward circular economy, enterprises are concerned about not only environmental sustainability, but also operational costs and profits; Material Flow Cost Accounting (MFCA) is hence commonly used for analyses on business. By integrating data on material flows and costs, MFCA is capable of depicting clearly the physical and cost flows in manufacturing processes, and enables enterprises to attach equal importance to corporate development, resource efficiency and ecological environment; flow directions of raw materials and energy can be firmly grasped, revealing raw material losses and material treatment costs that are easily ignored.

Based on material flow analysis, relevant assessment indicators can be used to evaluate the effectiveness of circular transition, such as the Emergy indicators that summarize the flows in a common basis (Geng et al. 2013). The goal of developing a circular economy is to facilitate the decoupling of economic development from resource consumption. Resource productivity, defined as "GDP/natural resource consumption," is an important indicator for evaluating such decoupling and applied by governments to assessing the implementation of sustainable materials management. For businesses, effectiveness of the transition to a circular model can be evaluated using circularity indicators (EMF 2015b); the products of businesses can be assessed based on each stage of their life cycle, and scored in terms of their circularity. This assessment approach can be used with risk indicators to consider additional risks, such as material prices fluctuation, supply chain risk, and toxicity.

6.3.2 Evaluation and Decision-Making Processes

International organizations advocating circular economy have put forth business models with categorization and generalization approaches varied with their respective emphases (Accenture 2014; EMF 2015c; Circle Economy 2016; Forum for the Future 2016; BSI 2017). Actually, business models are merely one of the essential procedures within the transition course toward circular economy, be it the five steps proposed by 2Cbizz in 2013 to guide conversion of linear economy issues into business opportunities for circular economy, the five steps proposed by WBCSD in 2016 to facilitate an action plan on circular economy (WBCSD 2016), or the 8-step process of transition proposed by BSI in 2017, wherein the circular transition path is described with a complete flowchart in accordance with project management thinking (BSI 2017). For these processes it is recommended that diverse assessment tools should be used in different procedures to explain quantitatively the circular economy transition path.

Take BS 8001:2017 proposed by BSI in June 2017 as an example. It provides a guide to the flexible framework for transition toward circular economy, and is the first standard for circular economy in the world. To build a relatively complete transition framework, it attempts to incorporate the steps of project management thinking, to integrate the concepts and analysis tools regarding circular economy. The primary objective of BS 8001 is to clearly define and unify the concepts, terms, scopes, and business models regarding circular economy, and develop a common language through unified standards and definitions, in order to accelerate cooperation and development of circular economy. To help enterprises transition from business operation modes of linear economy into those of circular economy, the guide offers principles and execution strategies for enterprises irrespective of scale, geographical location, or product or service form, and proposes fairly complete circular business models. BS 8001:2017 Framework for implementing the principles of the circular economy in organizations—Guide proposed a flexible framework for circular transition, including eight steps guiding enterprises to transition toward circular business models. “Flexible” means that enterprises can decide by themselves which step to begin with according to their own maturity of circulation. The eight steps are sequentially enumerated only for the purpose of providing a clear descriptive framework; in practice, depending on their maturity of circulation, enterprises may iterate and/or amend certain steps. Specifically, the framework comprises the following eight steps: (1) framing, (2) scoping, (3) idea generation, (4) feasibility evaluation, (5) business case development, (6) piloting, (7) implementation, and (8) review and reporting. At each step, BS 8001 provides a check function, which serves as a reminder that the outputs of each step should comply with the six principles of circular economy and the core idea of circular business model, and that progression to the next step requires approval or authorization by superior executives. The objective and output for each of the eight steps are summarized as shown in Table 6.3 (Hung 2018).

Centering on ideas of the transition path toward circular economy, the foresaid eight steps can be generalized into three stages (as shown in Fig. 6.4):

1. Explore ideas: how to identify problems and find their solutions? (how to explore the business opportunities of circular economy).

   In face of the innovation as well as systems thinking and operational changes necessitated by circular economy, the primary challenges come from the three earliest steps of transition: framing, scoping, and idea generation. These steps deal with how an enterprise reexamines itself, evaluates the current status, finds problems, and defines opportunities, when confronted with innovative issues, knowledge systems, or domains. To satisfy the needs of this exploratory stage, qualitative methods can be applied such as checklist or rating table, stakeholder analysis, brainstorming, expert consultation, and case studies, while the current extent of circulation can be quantified by applying MFA, MFCA, and circularity indicators.
2. Formulate ideas: how to evaluate which idea should be adopted? (how to select a circular idea).

   After exploring various ideas, feasible ones can be formulated. At this stage, idea feasibility and business cases can be described qualitatively by applying circular business model or prototyping. In addition, the economic, environmental, and social impacts of feasible ideas or technologies can be quantified by applying LCA or its extension, cost–benefit analysis, and health risk assessment.
3. Implement ideas: how to evaluate the effectiveness of an idea? (how to evaluate sustainability performance).

For the stages of piloting, implementation and review, the circular economy performance indicators at the corporate level are yet to be developed and defined; however, the economic, environmental, and social impacts after transition can still be explored through LCA and its extension. Results thereof can serve as negotiation

Table 6.3 Steps of transition toward circular economy in BS 8001 (BS 8001, 2017; Hung 2018)

Step	Objective	Output
(1) Framing	Understand the relationship between the enterprise and circular economy, to decide where to begin with	1. Identify key resources 2. Draw a stakeholder relationship diagram 3. Create communication documents on circular economy
(2) Scoping	Understand the potential opportunities and requirements for circular economy, set the boundaries, establish visions, and formulate strategies	1. Create a system diagram 2. Create a circulation vision, strategies, and a roadmap 3. Form a project team
(3) Idea generation	According to the problems or opportunities identified at Step (2), make a list of ideas and sort them according to the circulation vision, targets, and strategies	1. Generate a list of prioritized ideas
(4) Feasibility evaluation	Evaluate the feasibility of the ideas generated at Step (3)	1. Prepare a feasibility evaluation report 2. Confirm ideas
(5) Business case development	Develop business cases to ensure the availability of resources for piloting, and then implement, scale up, and officially launch the business model	1. Construct detailed and complete business cases
(6) Piloting and prototyping	Verify feasibility of the idea by piloting small-scale tests	1. Produce a Piloting plan and obtain piloting results
(7) Delivery and implementation	Scale up or officially launch the proven transition method	1. Indicate follow-up review indicators
(8) Review and reporting	Build a follow-up mechanism to ensure smooth implementation and continued circular transition	1. Control report 2. Regular progress report

information regarding transition difficulties and market acceptance consultation, thus facilitating transition toward circular economy.

It is advisable that different evaluation tools be applied to reach varying goals of the above stages; quantitative evaluation tools mainly include MFA, LCA, cost–benefit analysis, and health risk assessment.

6.4 Applications

To demonstrate the applications of the framework presented in earlier sections, a case study of the transition paths of polypropylene in the automotive industry toward circular economy is described here. As a lightweight, multifunctional, and

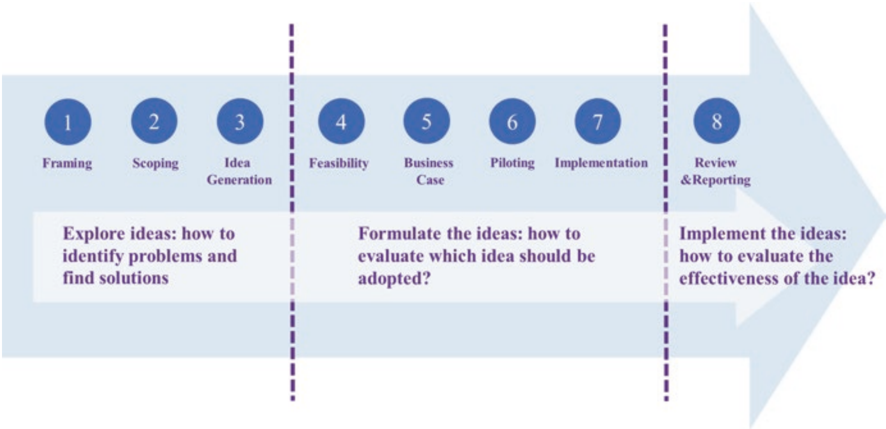


Fig. 6.4 Eight steps at three stages of transformation toward circular economy (Hung 2018)

durable material, plastic plays an important role in the development toward sustainability and resource efficiency. It acts as a critical material in the packaging, building materials, automotive, and renewable energy industries. Despite its various advantages, the drawbacks of today's plastics economy are becoming increasingly prominent. Take plastic packaging materials as an example. Economic losses due to one-time use amount to nearly 95% of the value of plastic packaging materials, equivalent to US$8–12 billion annually. Only 5% of the plastic is recycled and reused (EMF 2016b), most of which ending up in low-value products. To effectively improve the circularity of plastic, strategic solutions should be devised from the product life cycle perspective.

Plastic comes in many different types, among which polypropylene (PP) enjoys the largest demand. According to the survey of the Plastics Europe Market Research Group in 2015, the global demand for PP accounted for 23% of all plastics, surpassing that for PVC, the second most popular plastic, by 7% (PEMRG 2016). This section illustrates the transition process mentioned above by discussing the transition paths of PP in the automotive industry toward circular economy.

6.4.1 Step 1 Framing

The reuse of PP is crucial to the reuse of automotive plastics because automotive PP accounts for around 25–50% of all automotive plastics (Satoru et al. 2010; European Commission DG ENV 2011; Plastics market watch 2016). The PP used in each vehicle weighs approximately 36 kg (American Chemistry Council 2019). PP is mainly used in making car bumpers (including the side moldings on the car body) and lead acid battery cases, which respectively take up 23% and 1% of the total weight of automotive plastics (Nyamekie 2012). Due to its hydrophobicity, large

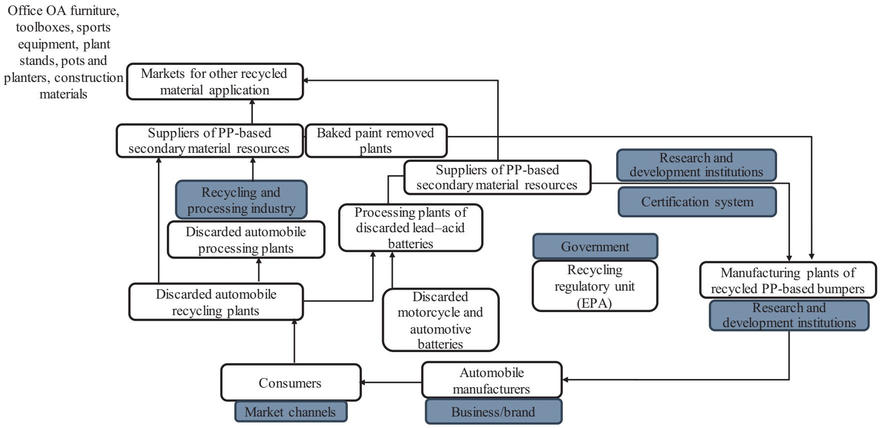


Fig. 6.5 The stakeholder ecosystem map

molecular mass, and lack of functional group, PP cannot be easily decomposed and is categorized as a nonbiodegradable plastic; hence, waste PP tends to accumulate in the natural environment, leading to negative environmental impacts (Tokiwa et al. 2009; Arkatkar et al. 2009).

Data on PP usage in the USA and Canada revealed that the amount of PP used in vehicles only increased slightly during the period of 2006–2016, but the proportion of PP in the automobile showed an upward trend; this indicates that the relative importance of PP has gradually increased compared with other types of automotive plastics.

Figure 6.5 summarizes the stakeholders related to PP-based car bumpers in the automotive industry. Besides the automotive industry and consumers that use PP-based bumpers, recycling of PP also involves discarded automobile processing plants, lead acid battery processing plants, and manufacturing plants of recycled PP-based bumpers. The government should play active roles in, to name a few, supervising the industry and promoting a certification system, to facilitate subsequent formulation of communication documents and bring synergy along the path toward circular economy.

6.4.2 Step 2 Scoping

The main approaches for processing waste PP include sanitary landfills, incineration (energy recovery), and resource recycling. With respect to sanitary landfills, although PP is not susceptible to biodegradation and hence does not emit greenhouse gases, landfills spoil the visual landscape, occupy land resources, and unnecessarily squander PP material resources; hence, they are not the optimal method for long-term waste management. Meanwhile, incineration can recycle the chemical energy in plastics, and incinerators that meet the waste emission and treatment standards, in most cases, exert minimal impact on the environment; however, this approach still emits a large amount of carbon dioxide and spends PP resources for disproportionate return (European Commission DG ENV 2011). Lastly, resource recycling also results in environmental impacts such as greenhouse gas emission and water pollution, as energy input is necessary for both transportation and processing; however, in comparison with landfilling and incineration, its environmental impact remains relatively mild. The overall environmental impact associated with recycled PP is 10–89% less severe than that caused by virgin PP. For instance, recycled PP incurs 50% less CO_2 emission, 65% less PO_4 emission, 29% less water consumption, and 78% less petroleum consumption than virgin PP (Yin et al. 2016). Based on the consideration of overall environmental impact, recycling waste PP does less harm; in addition, the economic value of recycled PP is retained by mixing it into car bumpers. Therefore, as an illustration, the system boundaries only consider the possible impact and benefits associated with the recycling of PP-based bumpers, as shown in Fig. 6.6.

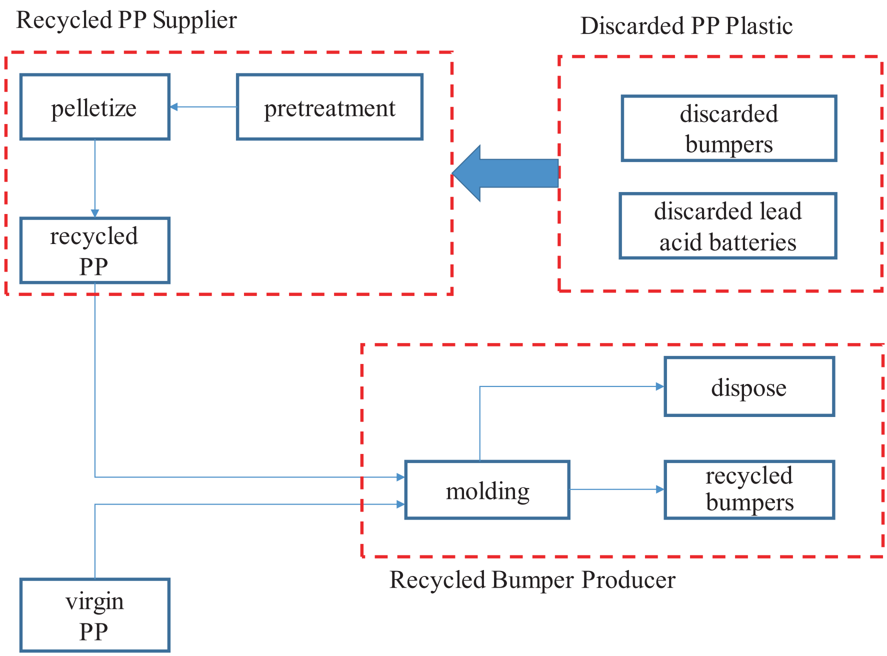


Fig. 6.6 The system boundary of PP-based car bumpers recycling

6.4.3 Step 3 Idea Generation

Of the five types of circular business models described previously, the value of recycled PP-based bumpers is created through practices of reverse logistics such as resource recovery, product life extension, and sharing platforms. At present, resource recovery is the most common business model. The circular economy of PP-based bumpers also adopts this prevalent business model, which contemplates the possibility of recreating economic value of recycling of discarded lead acid battery casings and scrapped bumpers to produce remade bumpers. Remade bumpers may be manufactured from discarded lead acid batteries, whose casings provide the waste PP material to be mixed with virgin PP for manufacturing recycled PP. As for the proportion of recycled materials in remade bumpers, interviews with manufacturers indicated that the maximum percentage is set as 30% to ensure quality of the latter.

In regard to remanufacturing scrapped bumpers into remade ones, the technical difficulties of the process lie in separating the baked paint and coatings. The separation technologies have been matured and applied to practical manufacturing process of remade bumpers. Due to poorer mechanical strength of waste PP, addition of virgin PP during the recycling process is also necessary.

Whereas the value chain of remade bumpers using discarded lead acid batteries as feedstock is essentially an open loop, that using scrapped bumpers would be more consistent with the recent appeal for enterprises to transition toward a closed loop. Such transformation may change the stakeholder relationships along with the economic and environmental impact involved. Therefore, the feasibility assessment will stress on how to strike a balance between the environmental and economic aspects to achieve the transition paths toward a circular economy of PP-based bumpers.

6.4.4 Step 4 Feasibility Assessment

The differences in the above transition paths toward a circular economy result in different value chains and impacts. Figure 6.7 shows the life cycle of remade bumpers manufactured from discarded lead acid battery casings, the arrows denoting the flow directions of PP. The main material inputs in the life cycle include virgin PP and discarded lead acid battery casings, and the outputs include remade PP-based bumpers and waste plastic generated during the machine milling and pressure and torsion testing in the manufacturing plants. The recycling and processing of PP are mainly undertaken by processing plants of discarded lead acid batteries, suppliers of PP-based secondary material resources, and manufacturing plants of remade PP-based bumpers. The PP casings of lead acid batteries are first separated and stored temporarily by processing plants. Afterward, suppliers of PP-based secondary material resources acquire the casings from processing plants for further processing, which includes pulverization, dehydration, drying, and granulation into

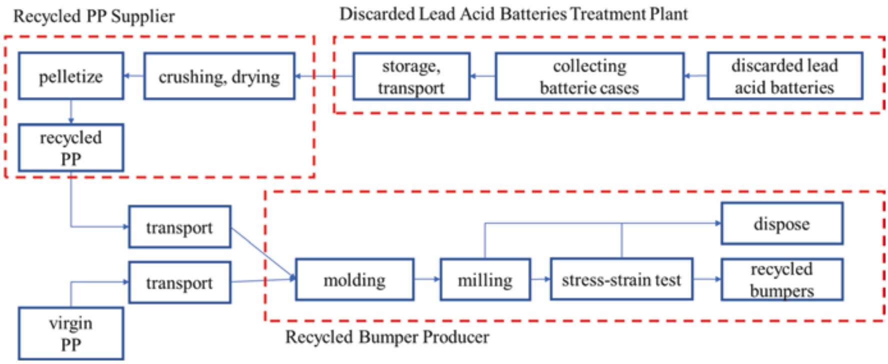


Fig. 6.7 Life cycle of the manufacture of recycled bumpers using discarded lead acid battery casings as raw materials

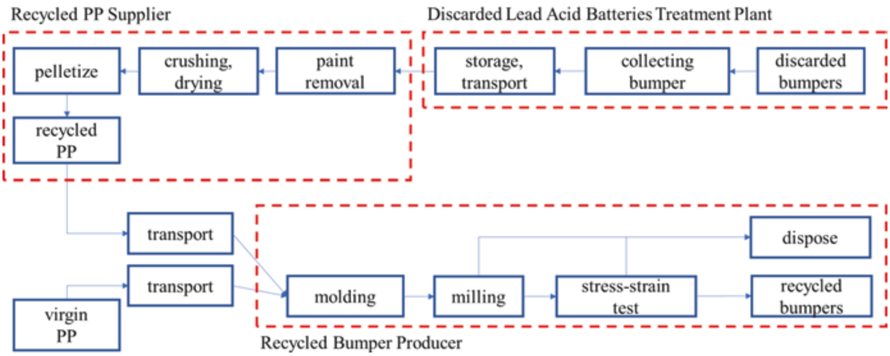


Fig. 6.8 Life cycle of the manufacture of recycled bumpers using scrapped bumpers as raw materials

recycled PP granules. The granules are then transported to the manufacturing plants as feedstock to be mixed with virgin PP granules, and some of them are discarded at the machine milling and pressure and torsion testing stages; the remaining PP is manufactured into remade bumpers (European Commission DG ENV 2011; Kozderka et al. 2017). There are five stakeholders involved in this value chain—the processing plants of discarded lead acid batteries, suppliers of PP-based secondary material resources, manufacturing plants of virgin PP, manufacturing plants of remade PP-based bumpers, and the transportation industry (European Commission DG ENV 2011; Kozderka et al. 2017).

Figure 6.8 illustrates the life cycle of the remanufacture of scrapped bumpers into remade bumpers. This transition path differs from the former in the supply of raw materials—its recycled materials come from scrapped bumpers dismantled by discarded automobile recycling plants; thus, the processing procedure also differs accordingly. Suppliers of PP-based secondary material resources must remove the baked paint and coatings on the surface of PP materials before subsequent processing, in order to prevent contamination of the recycled PP and resultant damage in mechanical properties (Zhao and Chen 2015). While the stakeholders involved in this process are almost identical to those in the recycling of discarded lead acid battery casings, the distinction lies in the suppliers of materials, as the recycled materials in this case come from waste from dismantling at discarded automobile recycling plants.

To conduct life-cycle assessment, we can define the demand for bumper PP as the functional unit of each transition path, to evaluate respective weights of the stakeholders' roles. Based on the life cycle of each path, an inventory of resource inputs, energy demands, pollutant emission and waste generation during the recycling process should be established. Both the immediate recycling process and the acquisition of energy, water, and other raw materials or additives may lead to air pollution, emission of water pollutants and waste generation (midpoint level), resulting in corresponding human health issues, ecosystem damages, climate change, and resource and energy depletion (endpoint level). A systematic analysis of these impact hot spots in each path, along with indicators like resource efficiency and circularity, should be conducted in order to explore whether the path with the lowest environmental impact is the optimal path for transition toward circular economy.

Apart from environmental assessment, economic assessment is also necessary for analyzing the potential sources and effectiveness of value creation in each path toward circular economy. For instance, regarding the value created by cost reduction, an in-depth investigation should be performed on whether there is any transfer or reduction of stakeholders' interests within the system boundaries, and related supporting measures or strategies should be formulated accordingly. As for value creation by behavioral changes, attribution of rights and duties during such behavioral changes should be pondered to prevent any possible disputes; the related regulations and supporting measures must also be considered in the meantime. If necessary, the supporting measures and strategies can be incorporated into the assessment system for a more comprehensive and systematic analysis of the pros and cons of each path.

6.4.5 Step 5 Business Case Development

According to the problems or opportunities identified in the previous steps and the feasibility analysis of each path, the circular business model selected for launch is proposed. As one of the tools for developing business models, business model canvas, a visualized and qualitative business development tool proposed by Osterwalder and Pigneur (2010), can be used. To further meet the need of the systemic design of a circular economy, augmented versions have been proposed by incorporating the concepts and principles of circular economy (Lewandowski 2016; Mentink 2014; Antikainen and Valkokari 2016). Elements of a business model canvas include the following: (1) business ecosystem and organizational culture, which are ramified into external factors such as market trends, domestic regulations and policies, technologies, and social acceptance and internal factors such as organizational culture and acceptance; (2) key partnerships, which include networks and types of collaboration; (3) key activities, which include optimization of product performance, product design, engagement of related partners and stakeholders, product remanufacturing and recycling, and related alternative technologies; (4) key resources, which include materials with better performance, regeneration and restoration of natural capital, virtualization of materials, and recovered resources (products, components, and materials); (5) value proposition, which includes product-service systems, circular products, virtualized services, and customer incentives for take-back; (6) customer relationships, which encompass production orders, customer advice, and social marketing strategies and community partnerships; (7) channels, such as virtualized channels; (8) take-back systems, which include take-back management and channels; (9) customer segments; (10) cost structure, which includes evaluation standards, preferential prices for customers, and material flow cost accounting criteria; (11) revenue streams such as input, availability, utility, performance, and value of recovered resources; (12) sustainability benefits, such as environmental benefits (resource productivity, environmental impacts, etc.) and social benefits (reinforcement of local communities, creation of employment opportunities, etc.). The project team should list as many required elements as possible and eventually construct a business model canvas to facilitate subsequent tryout of the transformation path.

Having the business case established, it calls for **Step 6. Piloting and prototyping**, **Step 7 Delivery and implementation**, and follow-up evaluation with **Step 8 Review and reporting** to repeatedly promote transition of the automotive industry toward a circular economy of PP bumpers. The tryout plan and verification of feasible idea during the process of piloting and prototyping can increase the chance of success in official implementation. Nevertheless, there might be unexpected consequences after official implementation; through control report and regular progress report to build subsequent control and follow-up are key to ensuring smooth implementation and sustained transition toward a circular economy.

6.5 Conclusion

We are facing the grand challenge of resource depletion and environmental impact. The key to reducing the pressure of resource and environmental issues while maintaining economic and societal growth is to change the way resources are used in our economic system. This calls forth change of the governance mechanism, integration of industries, redesign of infrastructure, and formation of partnerships. The Resource Efficiency Flagship Initiative proposed by the EU emphasized that following the existing linear economic model leads to a dead end; transitioning toward a circular economy is the only way to enhance the efficiency of resource utilization, open up opportunities for economic development, improve productivity, drive down production costs, and maintain competitiveness.

It has been estimated that the EU's continuous development toward a circular economy—through reuse, remanufacturing, and product recycling systems in industries, as well as technological revolution—can increase resource productivity by 3% annually. By 2030, the primary resource expenditure is estimated to be cut by €0.6 trillion per year. In addition, nonresource and environmental external benefits worth €1.2 trillion would be generated; overall, the annual benefits created by a circular economy could total up to €1.8 trillion (EMF 2015a). The EU's development of a circular economy can enhance environmental resilience; by 2030, CO_2 emission and resource consumption are estimated to be reduced by 48% and 32%, respectively. In the future, environmental benefits can be significantly increased through sharing, optimization, recycling, virtualization, and innovative technologies; by 2050, resource consumption is estimated to be cut by 53%.

Transitioning toward a circular economy is an important path toward sustainability from the viewpoint of resource efficiency. The 17 SDGs can be considered as the most pressing problems of human civilization in need of solutions. They are also the key subjects of enterprises in the integration of social and economic responsibilities and creation of shared values. At the core of such quest for sustainability, realization of a circular economy facilitates promotion of multiple SDGs; both the governments and the enterprises should reflect on relevant strategies sooner rather than later. The transition procedure, framework, and related assessment methods discussed previously can serve as references for practical implementation.

Circular economy can be regarded as an important path toward sustainable urban governance; the principles of circular economy can help achieve optimal energy and resource management in cities (EMF 2016a). Sustainable cities are also an important topic in sustainable development. The Reference Framework for Sustainable Cities (RFSC 2016) established in Europe is an online toolkit designed to help cities evaluate the progress of their sustainable urban development. It covers 5 main pillars including the environment, economy, society and culture, space, and governance as well as 30 objectives. Cities can communicate and cooperate with one another through the evaluation and formulate comprehensive strategies for urban development.

Sustainable governance of cities should take the overall urban system perspective to analyze the status of urban development. The inflow, outflow and stock of resources and solid materials (construction materials in particular) may differ significantly in growing and shrinking cities; hence, different governance methods are required. In expanding cities, accumulated construction materials may bring substantial environmental impact, but these solid materials may also become secondary material resources. In light of these secondary material resources that exist in the urban environment, urban planner Jane Jacobs proclaimed that "cities are the mines of the future" (Jacobs 1961). This prospect was based on the fact that considerable quantities of materials were flowing from mines into cities, where they were used in construction and infrastructure. These urban mines might provide an alternative to conventional mines in the earth's crust. Since around 2010, the vision for urban mining has been upgraded in the field of resource and waste management; urban mining has become a synonym for the recovery of secondary resources from products concentrated in urban areas (Graedel 2011; Johansson et al. 2013; Que et al. 2018). It focuses on different types of urban mineral deposits such as constructions and infrastructure (Ergun and Gorgolewski 2015; Wallsten et al. 2013) and landfills (Bockreis and Knapp 2011) or specific materials (Simoni et al. 2015; Wen et al. 2015). The mining potential depends on a wide array of driving factors including the future usability of urban mine waste, waste-related legislation, as well as the production costs of secondary resources and revenues obtained from the commodity market.

The pursuit of resource efficiency and resilience to decouple resource consumption and environmental impact from economic activities leads to important research directions. The endeavors on circular economy and sustainable cities have great potential to inspire innovations and practices on the journey toward sustainability.

References

ABCE (Advisory Board for Circular Economy). (2017). The Advisory Board for Circular Economy Recommendations for the Danish Government.

Accenture. (2014). *Circular advantage: Innovative business models and technologies to create value in a world without limits to growth*. Chicago: Accenture.

Antikainen, M., & Valkokari, K. (2016). Framework for sustainable circular business model innovation. *Technology Innovation Management Review, 6*(7), 5–12.

Arkatkar, A., Arutchelvi, J., Sudhakar, M., Bhaduri, S., Uppara, P. V., & Doble, M. (2009). Approaches to enhance the biodegradation of polyolefins. *The Open Environmental Engineering Journal, 2*, 68–80.

American Chemistry Council (2019) Plastics and Polymer Composites in Light Vehicles. https://www.automotiveplastics.com/blog/2019-plastics-and-polymer-composites-in-light-vehicles/

Baccini, P., & Brunner, P. H. (2012). *Metabolism of the anthroposphere*. Cambridge: The MIT Press.

Bockreis, A., & Knapp, J. (2011). Landfill mining – Deponien als Rohstoffquelle. *Ö sterreichische Wasser- und Abfallwirtschaft, 63*(2), 70–75.

Brunner, P. H., & Rechberger, H. (2004). *Practical handbook of material analysis*. Retrieved from https://iwr.tuwien.ac.at/fileadmin/mediapool-ressourcen/MFA_Handbook/solutions.pdf

BSI (British Standards Institution). (2017). *BS 8001:2017. Framework for implementing the principles of the circular economy in organizations – Guide*. London: The British Standards Institution.

Circle Economy. (2016). *Master circular business with the value hill*. Amsterdam: Circle Economy.

Curran, M. A. (1996). *Environmental life-cycle assessment* (Vol. 1, p. 179). New York: McGraw-Hill Press.

EC (European Commission). (2014). *Scoping study to identify potential circular economy actions, priority sectors, material flows and value chains*. Luxembourg: DG Environment.

EC (European Commission). (2015). *Circular economy strategy: Closing the loop—An EU action plan for the circular economy*. Retrieved from http://ec.europa.eu/environment/circular-economy/index_en.htm

EC (European Commission). (2017). *On the implementation of the Circular Economy Action Plan*. Retrieved from http://ec.europa.eu/environment/circular-economy/implementation_report.pdf

EEB (European Environmental Bureau). (2015). Circular Economy Package 2.0: Some ideas to complete the circle.

EMF (Ellen MacArthur Foundation). (2012). *Towards the circular economy Vol. 1: An economic and business rationale for an accelerated transition*. Retrieved from https://www.ellenmacarthurfoundation.org

EMF (Ellen MacArthur Foundation). (2013). *Towards the circular economy Vol. 1: Opportunities for the consumer goods sector*.

EMF (Ellen MacArthur Foundation). (2015a). *Towards a circular economy: Business rationale for an accelerated transition*. Retrieved from https://www.ellenmacarthurfoundation.org

EMF (Ellen MacArthur Foundation). (2015b). *Circularity indicators: An approach to measuring circularity*. Cowes: Ellen MacArthur Foundation.

EMF (Ellen MacArthur Foundation), SUN, & McKinsey. (2015c). *Growth within: A circular economy vision for a competitive Europe*. Ellen MacArthur Foundation: Cowes.

EMF (Ellen MacArthur Foundation). (2016a). *Circular economy in India: Rethinking growth for long-term prosperity*. Retrieved from https://www.ellenmacarthurfoundation.org

EMF (Ellen MacArthur Foundation). (2016b). *The new plastics economy: Rethinking the future of plastics*. Retrieved from https://www.ellenmacarthurfoundation.org

Ergun, D., & Gorgolewski, M. (2015). Inventorying Toronto's single detached housing stocks to examine the availability of clay brick for urban mining. *Waste Management, 45*, 180–185.

European Commission DG ENV. (2011). *Plastic waste in the environment*. Paris: BIO Intelligence Service.

Forum of the Future & Unilever. (2016). *Circular Business Models*. Retrieved from https://www.forumforthefuture.org/project/circular-economy-business-modeltoolkit/verview

French Ministry of the Environment (2018) Circular economy roadmap: The French experience, French Ministry of the Environment.

Geissdoerfer, M., Morioka, S., de Carvalho, M., & Evans, S. (2019). Business models and supply chains for the circular economy. *Journal of Cleaner Production, 190*, 712–721.

Geng, Y., Sarkis, J., Ulgiati, S., & Zhang, P. (2013). Measuring China's circular economy. *Science, 339*, 1526–1527.

Genovese, A., Acquaye, A., Figueroa, A., & Koh, S. (2017). Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. *Omega, 66*, 344–357.

Gigli, S., Landi, D., & Germani, M. (2019). Cost-benefit analysis of a circular economy project: A study on a recycling system for end-of-life tyres. *Journal of Cleaner Production, 229*, 680. https://doi.org/10.1016/j.jclepro.2019.03.223.

Graedel, T. (2011). The prospects for urban mining. *Bridge, 41*, 43–50.

Haupt, M., & Zschokke, M. (2017). How can LCA support the circular economy? *The International Journal of Life Cycle Assessment, 22*(5), 832–837.

Hung, P. Y. (2018). *The transition process and tools of moving towards a circular business model*. Graduate Institute of Environmental Engineering, National Taiwan University Master Thesis.

Huysveld, S., Hubo, S., Ragaert, K., & Dewulf, J. (2019). Advancing circular economy benefit indicators and application on open-loop recycling of mixed and contaminated plastic waste fractions. *Journal of Cleaner Production, 211*, 1–13.

Iacovidou, E., Millward-Hopkins, J., Busch, J., Purnell, P., Velis, C., Hahladakis, J., Zwirner, O., & Brown, A. (2017). A pathway to circular economy: Developing a conceptual framework for complex value assessment of resources recovered from waste. *Journal of Cleaner Production, 168*, 1279–1288.

Ingrao, C., Messineo, A., Beltramo, R., Yigitcanlar, T., & Ioppolo, G. (2018). How can life cycle thinking support sustainability of buildings? Investigating life cycle assessment applications for energy efficiency and environmental performance. *Journal of Cleaner Production, 201*, 556–569.

Jacobs, J. (1961). *The death and life of great American cities*. New York: Random House.

Jin, I. (2016). Circular economy policy in Korea. In V. Anbumozhi & J. Kim (Eds.), *Towards a circular economy: Corporate management and policy pathways. ERIA research project report 2014-44* (pp. 163–184). Jakarta: ERIA.

Johansson, N., Krook, J., Eklund, M., & Berglund, B. (2013). An integrated review of concepts and initiatives for mining the technosphere: Towards a new taxonomy. *Journal of Cleaner Production, 55*, 35–44.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, 127*, 221–232.

Kozderka, M., Rose, B., Bahlouli, N., Kočí, V., & Caillaud, E. (2017). Recycled high impact polypropylene in the automotive industry-mechanical and environmental properties. *International Journal on Interactive Design and Manufacturing, 3*, 737–750.

Lacovidou, E., Millward-Hopkins, J., Busch, J., Purnell, P., Velis, C., et al. (2017). A pathway to circular economy: Developing a conceptual framework for complex value assessment of resources recovered from waste. *Journal of Cleaner Production, 168*, 1279–1288.

Lavers, A., Kalmykova, Y., Rosado, L., Oliveira, F., Laurenti, R., & Rydberg, T. (2019). Combining material flow analysis with life cycle assessment to identify environmental hotspots of urban consumption. *Journal of Cleaner Production, 226*, 526–539.

Lewandowski, M. (2016). Designing the business models for circular economy—Towards the conceptual framework. *Sustainability, 8*(1), 43.

Lowe, E., & Evans, L. (1995). Industrial ecology and industrial ecosystems. *Journal of Cleaner Production, 3*(1–2), 47–53.

Mentink, B. (2014). *Circular business model innovation: A process framework and a tool for business model innovation in a circular economy*.

Ministry of Infrastructure and the Environment. (2014). *Implementation of the waste to resource programme*.

Ministry of the Environment (Japan). (2017). *Progress of the fundamental plan for establishing a sound material-cycle society*.

NDRC (National Development and Reform Commission) of the People's Republic of China. (2017). *Circular development and leading action*.

Nyamekie, P. (2012). *Re-use and re-cycling of automobile plastics – A step to manage plastic waste in Ghana*. Helsinki: Arcada University of Applied Sciences.

OECD. (2019). *Business models for the circular economy: Opportunities and challenges for policy*. Paris: OECD Publishing.

Osterwalder, A., & Pigneur, Y. (2010). *Business model generation: A handbook for visionaries, game changers, and challengers*. New York: Wiley.

PEMRG. (2016). *Consultic marketing & Industrieberatung*. Retrieved from Plastics Europe Market Research Group.

Pieroni, M., McAloone, T., & Pigosso, D. (2019). Business model innovation for circular economy and sustainability: A review of approaches. *Journal of Cleaner Production, 215*, 198–216.

Plastics Market Watch. (2016). *Automotive recycling devalued is now revalued*. Washington, DC: Plastics Market Watch.

Que, S., Awuah-Offei, K., Wang, L., Samaranayake, V., Weidner, N., & Yuan, S. (2018). Individual preferences for mineral resource development: Perspectives from an urban population in the United States. *Journal of Cleaner Production, 189*, 30–39.

RFSC. (2016). Retrieved from http://rfsc.eu

Saavedra, M. B. Y., Iritani, D. R., Pavan, A. L. R., & Ometto, A. R. (2018). Theoretical contribution of industrial ecology to circular economy. *Journal of Cleaner Production, 170*, 1514–1522.

Satoru, M., Tsuyoshi, W., & Susumu, K. (2010). Polypropylene compounds for automotive applications. *SUMITOMO KAGAKU, pp., 2010*, 1–16.

Schroeder, P., Anggraeni, K., & Weber, U. (2018). The relevance of circular economy practices to the sustainable development goals. *Journal of Industrial Ecology, 23*, 77. https://doi.org/10.1111/jiec.12732.

Simoni, M., Kuhn, E. P., Morf, L. S., Kuendig, R., & Adam, F. (2015). Urban mining as a contribution to the resource strategy of the Canton of Zurich. *Waste Management, 45*, 10–21.

Stahel, W. R., & Clift, R. (2016). Stocks and flows in the performance economy. In R. Clift & A. Druckman (Eds.), *Taking stock of industrial ecology*. Cham: Springer.

Tokiwa, Y., Calabia, B. P., Ugwu, C. U., & Aiba, S. (2009). Biodegradability of plastics. *International Journal of Molecular Sciences, 10*(9), 3722–3742.

Ünal, E., & Shao, J. (2019). A taxonomy of circular economy implementation strategies for manufacturing firms: Analysis of 391 cradle-to-cradle products. *Journal of Cleaner Production, 212*, 754–765.

Wallsten, B., Carlsson, A., Frändegård, P., Krook, J., & Svanström, S. (2013). To prospect an urban mine – Assessing the metal recovery potential of infrastructure "cold spots" in Norrköping, Sweden. *Journal of Cleaner Production, 55*, 103–111.

Wang, Y. S., & Ma, H. W. (2018). Analysis of uncertainty in material flow analysis. *Journal of Cleaner Production, 170*, 1017–1028.

WBCSD. (2016). *Unlocking more value with fewer resources a practical guide to the circular economy*.

Wen, Z., Zhang, C., Ji, X., & Xue, Y. (2015). Urban mining's potential to relieve China's coming resource crisis. *Journal of Industrial Ecology, 19*(6), 1091–1102.

WRAP. (2013). *On course for zero waste*.

Yin, S., Tuladhar, R., Sheehan, M., Combe, M., & Collister, T. (2016). A life cycle assessment of recycled polypropylene fibre in concrete footpaths. *Journal of Cleaner Production, 112*, 2231–2242.

Zhao, Q., & Chen, M. (2015). Automotive plastic parts design, recycling, research, and development in China. *Journal of Thermoplastic Composite Materials, 28*, 142–157.