Chapter 7
Materials Consumption and Solid Waste

by Michael Burger

Summary

The circular economy represents a powerful new paradigm for materials consumption and solid waste management. Instead of beginning with extraction and ending with waste, the circular economy begins with material already in use, or else material designed for iterative uses, moves through production and consumption, and into waste management, which secures a revived or altered source material, which in turn moves through production and consumption, and so on, over and over again. Achieving significant greenhouse gas reductions in this area requires widespread shifts in production and consumption toward what can be expressed succinctly in a familiar refrain: “reduce, reuse, recycle.” There are a number of legal pathways to achieving emissions reductions through materials consumption and solid waste management. Corporate governance as well as research and development of new materials can play a significant role, and significant advances can be made through regulatory interventions.

I. Introduction

The modern industrial economy can appropriately be thought of as linear in nature. Natural resources are extracted from the hinterlands in the form of, for instance, timber, minerals, or wildlife; transported from the periphery towards urban centers; converted into products through craft or manufacture; used by businesses or individual consumers; and then thrown away. This linear economy has succeeded in many respects. It has produced extraordinary economic development, and it has increased quality of life and human well-being in many places around the world. It has also frequently, and repeatedly, run into natural limits. There is only so much in the way of untapped natural resources. And there is only so much space in which to dispose of our waste. Moreover, the linear industrial economy has produced many forms of environmental pollution; at one point or another, citizens in the United States and elsewhere have concluded that streets, oceans, rivers, the soil itself, and the atmosphere are either entirely inappropriate disposal sites for solid waste or else require systems and standards to manage the associated risks and preserve certain amenities, such as non-contaminated beaches and open space. In addition, at every step of the process, from extraction through disposal, greenhouse gases (GHGs) are emitted. When a product winds up in a landfill or incinerated at a commercial facility, the GHG emissions that went into it—its embedded emissions—like the product itself, become waste. In some instances, as with food waste left to decompose or incineration of solid waste, the product itself converts into GHGs.

The limits confronting the linear economy, and the pollution problems it produces, will only become more intense in the coming years, as the earth’s population reaches an estimated 9.7 billion people by mid-century, including three billion new middle-class consumers, and the U.S. population increases by almost a third, to reach 417 million people by 2060. Human societies are rapidly depleting natural resources and degrading and destroying ecosystems, even as we are running out of land for waste

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disposal. Each of these problems is exacerbated by climate change, which puts new stresses on ecosystems and land use. What is more, we can no longer afford to either waste or release the embedded GHGs housed in products and materials. To achieve deep decarbonization, GHG emissions need to be reduced at every turn. Accordingly, there is a clear need for a new paradigm to inform and manage the material goods and services that constitute our real economy.

The circular economy represents one potential new paradigm, one which, due to its economic and ecological efficiencies, and its benefits for corporate performance and environmental quality, has quickly gained traction with businesses and environmental advocates alike. While the linear economy is defined by its progression toward material disposal, the circular economy is defined by its loop- ing materials back into utility—that is, by reuse, repair, repurposing, remanufacturing, and recycling. Instead of beginning with extraction of virgin material and ending with waste, the circular economy model begins with material already in use, or else material designed for iterative uses, moves through production and consumption and into waste management, which secures a revived or altered source material, which in turn moves though production and consumption, and so on. In this system, products and services are designed to enable more efficient circulation through a recurrent life cycle, with minimal loss of quality.

This chapter examines how the law may be used to facilitate a transition in materials and solid waste management that would contribute to deep decarbonization, setting forth a number of legal developments that could contribute to the eventual construction of a circular economy in the United States. For present purposes, however, it is necessary to cabin the concept of the circular economy. Taken to its logical extreme, the circular economy is an all-encompassing concept that requires a fundamental reorganization of property rights, food systems, energy systems, industrial systems, waste management systems, and, indeed, entire socioecological and economic systems. What is more, as the economy is global, a truly circular economy would also require global transformation. The intent here is to examine a more limited notion of the circular economy as a form of domestic industrial ecology, focused on the production and management of a limited universe of material goods and product-based services, principally materials and products that would otherwise be eventually managed as municipal and industrial solid waste. Moreover, the chapter does not aim to deal comprehensively with waste management as a means to reduce GHG emissions. For example, the chapter does not cover landfills, the primary source of direct waste-related GHG emissions, which are addressed in Chapter 33 (Methane). The chapter also does not cover wastewater management. (Wastewater does contribute some amount of GHGs to the nation’s total, and biosolids recovery may present some opportunity to recapture some of those emissions.) Nor does the chapter cover upstream management of food production, which is covered in Chapter 30, or industrial production, which is covered in Chapter 12.

With this version of the circular economy in mind, the desired shifts in production and consumption become somewhat easier to conceptualize. In fact, they can be expressed succinctly, and in an exceedingly familiar way: “reduce, reuse, recycle.” The available legal pathways towards these goals—reduction of raw material production and consumption, reuse of materials and products already in circulation, and recycling of materials that can no longer be reused in their current format—are also familiar. A noncomprehensive list includes, first and foremost, regulatory interventions such as recycling rules for various waste streams, including organic waste; mandatory solid waste management planning; materials and product content controls; and procurement policies. The list would also include funding and incentivizing research and development of new materials. Finally, innovations in retailer-consumer transactions and corporate governance can assist in the transition to a large-scale, closed-loop cycle of production and consumption. (Other legal techniques that attempt to alter personal behavior are discussed in Chapter 3.)
II. Characterization of the Circular Economy and Its Climate Benefits

A. A Brief History of the Circular Economy

According to the Ellen MacArthur Foundation, one of the most visible proponents of the circular economy concept, the idea of the circular economy draws from a number of influences, including the Cradle to Cradle concept and certification process and the publication of Walter Stahel’s Performance Economy in 2006. The foundation published Towards a Circular Economy in 2012, setting forth the case for adopting the circular economy as a mobilizing force for a more sustainable pattern of production and consumption. Since then, the foundation has released a number of reports, making the business case for a circular economy; explicating its implementation in sectors such as consumer goods, digital products, and plastics; and identifying critical policy choices for decisionmakers. Governments, international and national organizations, corporations, start-ups, and think tanks have caught on as well, and the concept enjoys an ever-increasing discursive impact. In addition to efforts undertaken by the European Union (EU), China, and Japan (discussed further below), the United Nations Environment Programme (UNEP), the U.S. Chamber of Commerce, and companies ranging in size and impact from Walmart and Dell to Looptworks and Thread have attached themselves to the circular economy. The U.S. Environmental Protection Agency’s (EPA’s) Sustainable Materials Management program also resonates with circular economy precepts.

B. The Effect of the Circular Economy on GHG Emissions

The precise effect a complete transition to a circular economy would have on U.S. GHG emissions is uncertain. (The Deep Decarbonization Pathways Project (DDPP) reports are directed at achieving an 80% reduction in U.S. GHG emissions by 2050. But they do not calculate emissions reductions to be achieved through improvements to materials management. Similarly, the Obama Administration’s United States Mid-century Strategy for Deep Decarbonization does not place any emphasis on materials manage-

tment or the circular economy. Yet, it seems intuitive that the circular economy will reduce GHG emissions waste, and therefore GHG emissions: when material wastes are reduced, reused, or recycled, less energy is needed to obtain raw materials, transport them, and manufacture them; when energy demand decreases, fewer fossil fuels are burned and less GHGs are emitted into the atmosphere. As noted in a 2015 UNEP report:

[Upstream actions to address the problem at source, such as designing out waste, preventing its generation and reusing products, have the potential for much greater carbon savings, as these displace greenhouse gas emissions across a wide range of sectors which would otherwise be incurred to provide the displaced products. Similarly, recycling replaces virgin materials at a much lower carbon cost and thus reduces emissions across the economy.]

In addition, with less organic material in the waste stream, one would expect fewer emissions to emerge from the waste’s decomposition.

Yet, understanding the real impact of a circular economy on GHG emissions is complicated. Many of the emissions reductions to be achieved through the circular economy are linked to emissions reductions that may be achieved in other sectors: from the nonroad vehicles and machinery that extract raw natural resources; from the vehicles, trains, and ships that transport materials from extraction to processing, from processing to retail, and from retail to consumption (Chapter 17 (Shipping)); from industrial facilities that manufacture the goods (Chapter 12 (Industrial Sector)); and from landfills and waste-to-energy facilities where goods wind up at the end of the linear progression (Chapter 33 (Methane)), among other places. If all of these other sectors are decarbonized through technological and legal innovations, then the GHG emissions impact of materials management will be decreased proportionally. Moreover, much of the circular economy concept depends on the prospects for manufacturing new materials that can endure multiple or even infinite use cycles without compromising quality, remanufacturing existing materials, and reusing existing products. These processes each require energy, and therefore may result in GHG emissions themselves, unless they are powered by carbon-free power and employ their own circular economy systems. A full accounting of the circular economy’s impact, then, would have to compare circular economy emissions with both the status quo alternative and with the deep decarbonization alternative that produces source-based reductions throughout a material’s life cycle.

15. See Global Solid Waste Management Outlook, supra note 4.
It is beyond the scope of this chapter to endeavor to extrapolate an estimate for U.S. GHG emissions reductions to be achieved through a circular economy.\textsuperscript{16} EPA’s Sustainable Materials Management program may provide useful information. EPA has conducted several comprehensive sector and systems analyses of materials management. For example, in a 2009 report, \textit{Opportunities to Reduce Greenhouse Gas Emissions Through Materials and Land Management Practices}, EPA determined that, as of 2006, GHG emissions from materials management amounted to 42% of total national emissions (29% from the provision of goods and 13% from the provision of food).\textsuperscript{17} The report also estimates the GHG reductions from a reduction in packaging (50% reduction = 40-105 million metric tons carbon dioxide equivalent (CO\textsubscript{2}e/year)), reduction in non-packaging paper products (50% = 20-70 million metric tons CO\textsubscript{2}e/year), extended life of personal computers (50% = 25 million metric tons CO\textsubscript{2}e/year), increased recycling of construction and demolition debris (100% = 150 million metric tons CO\textsubscript{2}e/year), increased recycling and composting of municipal solid waste (100% = 300 million metric tons CO\textsubscript{2}e/year), and increased composting of food scraps (100% = 20 million metric tons CO\textsubscript{2}e/year).\textsuperscript{18} Taking the most optimistic projections from EPA’s report, applying a “reduce, reuse, recycle” strategy to these key categories of solid waste could produce a GHG emission reduction of approximately 23% from the overall emissions directly and indirectly associated with materials management, or a total of 9.75% economy-wide emission reduction.\textsuperscript{19}

\textsuperscript{16} There are some interesting international points of comparison. UNEP has noted that some estimates conclude that a 15%-20% reduction in global GHGs could be achieved through a combination of waste prevention, landfill mitigation, waste diversion, waste-to-energy processes, recycling, and other types of solid waste management. See \textit{Global Solid Waste Management Outlook}, supra note 4, at 12. A report issued by the Club of Rome on the effects of a shift to a circular economy in Finland, France, the Netherlands, Spain, and Sweden estimates reductions in three potential circular economy scenarios: a 25% increase in energy efficiency, a 50% increase in renewable energy production, and material-efficient manufacturing processes with a 25% decrease in overall material input, and a 50% decrease in virgin material input. The report predicts that for each country there would be a roughly 65% cumulative reduction in GHG emissions if all three circular economy reduction scenarios were pursued. See \textit{Wijers & Skanberg}, supra note 6. EPA’s Waste Reduction Model (WARM) provides one potential starting point for a U.S. calculation. See EPA, \textit{Waste—Resource Conservation—WARM,} https://www3.epa.gov/warm/Warm_Form.html (last updated June 12, 2017). However, WARM does not account for many important sources of waste that would be affected by a shift to a circular economy, such as appliances, vehicles, or most e-waste.


\textsuperscript{18} Opportunities to Reduce Greenhouse Gas Emissions, supra note 17, at 4.

\textsuperscript{19} Under these projections, emissions reductions could total 670 million metric tons CO\textsubscript{2}e. As noted in the text above, services relevant to this chapter directly or indirectly account for 42% of U.S. emissions. In 2014, the total emissions from the United States were 6,870. Thus, materials management could account for 42% of 6,870, or 2,885 million metric tons CO\textsubscript{2}e. And 670 is 23.2% of 2,885; 9.75% of 6,875.

Thus, consideration of legal pathways based on circular economy concepts provides additional ways of achieving the 80% reduction goal identified in the DDPP reports. These additional pathways could speed up achievement of the required reduction; provide greater social, economic, or environmental benefits; or reduce costs. Calculating any emission reduction estimate depends on how one defines the system scope—that is, on which processes, materials, products, and wastes are included and which ones are not. The following section addresses some of the legal techniques that have been used to date to either implement circular economy reform, or else to target specific parts of the materials management puzzle.

### III. Legal Techniques for a Circular Economy

EPA estimates discussed above rely on achieving 100% recycling of municipal solid waste and composting of food scraps. At least one legal technique for achieving this extraordinary feat is relatively straightforward: new legislation at the federal level mandating that all municipal solid waste, including food scraps, be recycled or composted, with a delegation of authority to the states to establish solid waste management plans to achieve this goal. Similarly, reductions in the use of packaging material and non-packaging paper products consistent with EPA’s estimates could be achieved through new federal legislation that establishes a uniform, economy-wide set of materials requirements and quantity limits. The energy efficiency of personal computers (though not necessarily the expected life-span) could also be achieved through new federal legislation directing the U.S. Department of Energy to establish standards for personal computer manufacturers. (See Chapter 9 (Lighting, Appliances, and Other Equipment).)

In reality, action on any of these matters by the U.S. Congress is highly unlikely, if not entirely inconceivable, and materials consumption and waste management reform will never be nearly so neat in our federalist system. There simply is not a single formula for enacting a full, or even a partial, transition to a circular economy. However, there are some useful examples. For instance, there have been notable regulatory interventions: Japan, China, and the EU have each legislated broad reforms intended to address materials management in a systematic way and, to a greater or lesser degree, implement the circular economy idea. In the United States, states and local governments have been left to their own devices to innovate, producing a patchwork of approaches to addressing discrete parts of the materials management problem. Public and private research and development has also begun to introduce...
innovations that can contribute to the overall reduction in GHG emissions associated with our production, consumption, and management of remnant materials, and entrepreneurs and inventors have developed new materials that may help shape, in a literal sense, the content of the circular economy. Finally, corporations and industrial facilities have also, in a few instances, adopted private governance regimes oriented toward transitioning to a circular economy model. This section reviews some of the most notable developments to date.

A. Regulatory Interventions

I. Existing Approaches: Foreign Country Legislation

Circular economy reforms in Japan, China, and the EU offer some insight into what a legal transition might entail. In the wake of deep oil shortages brought on by the 1970s oil crises, Japan began its transition towards a circular economy. Its first comprehensive legislation, the Law for Promotion of Effective Utilization of Resources, was passed in 1991, and set out a legal framework for manufacturers, outlining mandatory take-back rules, recycling quotas, reuse guidelines, and waste byproduct limits. In the 1993 Basic Environment Law, Japan created an environmental council tasked with drafting an environmental plan that articulates basic principles for government, corporations, and citizens to promote environmental conservation. The 2000 Basic Law for Establishing a Recycling-based Society assigns basic waste management responsibilities to the national government, local governments, businesses, and citizens, and establishes an order of priority for waste management techniques: reduction, reuse, recycling, incineration, and proper disposal. Together, these three laws establish the general principles of reduction in front-end resource use, and recycling and reuse of resources at the end of their normal use cycle. These general principles are supported by specific protocols, consistent with circular economy concepts, that regulate the life-cycle management of products such as containers and packaging.

20. [Law for Promotion of Effective Utilization of Recyclables], Law No. 48 of 1991 (Japan).
21. [Basic Environmental Law], Law No. 91 of 1993 (Japan).
22. [Basic Law for Establishing a Recycling-based Society], Law No. 110 of 2000 (Japan).
23. [Law for Promotion of Sorted Collection and Recycling of Containers and Packaging], Law No. 112 of 1995 (Japan) (creating a national recycling policy guiding municipal sorting, collection, and recycling of glass, plastic, polystyrene, paper, and metal containers and packaging waste created by businesses and consumers).
24. [Construction Material Recycling Law], Law No. 104 of 2000 (Japan) (requiring recycling of concrete, iron, wood, and asphalt created as a result of construction, civil engineering, renovation, and demolition projects).
25. [Law on Recycling of Specified Kinds of Home Appliances], Law No. 97 of 1998 (Japan) (requiring consumers and retailers to return air conditioners, televisions, refrigerators and freezers, and washing machines and clothes dryers to manufacturers, and requiring manufacturers to accept and recycle the returned products).
26. [Food Recycling Law], Law No. 176 of 2001 (Japan) (establishing recycling targets for food manufacturers, food retailers, food wholesalers, and catering services/restaurants).
27. [End-of-life Vehicle Law], Law No. 87 of 2002 (Japan) (establishing a consumer paid recycling program for all four-wheel vehicles to collect chlorofluorocarbons, airbags, and shredder dust and to recycle auto parts).
28. [Act on Promoting Green Purchasing], Law No. 100 of 2000 (Japan).
30. Id. ch. 2, art. 16.
Localities in some 15 states and the District of Columbia have passed some form of plastic bag regulation. These regulations include outright bans on plastic bags, complete bans on all non-compostable bags, fees from one cent to 25 cents per bag sold, and mandatory recycling requirements. Some localities require a review of the plastic bag regulations if certain benchmark reductions in bag use are not reached by a given date. The overall purpose of these laws is to discourage customers from using non-compostable bags and to encourage both recycling of plastic bags and a switch to the use of reusable or paper bags.

Polystyrene bans have been enacted in municipalities in a number of states, including California, Florida, Maine, Maryland, Massachusetts, Michigan, New Jersey, New York, Oregon, Texas, and Washington, as well as the District of Columbia. In some instances, these bans are complete and no polystyrene products can be sold in that locality. In other instances, the ban applies only to specific industries (generally the restaurant industry, where a majority of the polystyrene packaging waste is produced) or specific polystyrene products (generally food ware). Other municipalities allow polystyrene products but require that they be either recyclable, compostable, returnable, biodegradable, or degradable. Whatever the level of the ban, the general goal of these ordinances is to reduce the amount of nondegradable polystyrene waste that is produced and that is landfilled.

The carbon footprints of plastic bags and polystyrene, on their own, are relatively small. In fact, from a climate perspective, plastic bags may well beat paper. However, other materials and products could arguably be made subject to similar local bans based on their carbon content. Effective life-cycle carbon assessment would be necessary to determine whether and how such approaches might be applied to materials and products in the climate change context.

### b. State Recycling and Extended Producer Liability Laws

As noted above, EPA has estimated that increasing the municipal solid waste recycling and composting rate nationwide to 100% would result in GHG emissions reductions of 300 million metric tons CO$_2$e/year. No states yet achieve anything like that rate, but they have...
experimented with a number of different approaches that could be utilized moving forward.

Some 19 states and the District of Columbia mandate recycling of at least one type of waste, by at least one category of waste producer. These regulations invariably cover yard waste, paper waste, office waste, batteries, bottles (glass, plastics, and aluminum), electronics, metals, plastics, and waste oil. In some states, these recycling laws are broad both in the sources of waste they regulate and the waste producers they regulate. California has sought to integrate recycling into its attempt to reduce GHG emissions under the Global Warming Solutions Act. Connecticut has recycling requirements for 15 of 25 listed types of waste and applies 13 of these requirements to all waste producers, including single-family homes, government agencies, and businesses. In other states, regulations cover fewer types of waste and fewer waste producers. Georgia, for example, only requires lead acid batteries to be recycled. South Dakota applies recycling requirements to nine types of waste, but only that produced by government agencies and universities.

Not all state recycling laws require actual recycling. Statewide bottle bills, for example, have been enacted in California, Connecticut, Delaware, Hawaii, Iowa, Maine, Massachusetts, Michigan, New York, Oregon, and Vermont. These bottle bills all follow the same general pattern of regulation. The first phase is a tax or fee on the producers of bottles. The exact types of containers covered by each state’s regulation vary but commonly apply to aluminum, metal, plastic, and glass containers that are used for certain or all types of beverages. The producers of these containers pay their tax or fee, otherwise known as a deposit, either directly to certified redemption centers or to the state, which then redistributes the fee, and pass on this increased price to customers. Customers must pay the normal market price of the beverage plus the deposit fee. This system has a two-fold advantage for resource managers. First, an increased price decreases demand, and thus the total number of bottles produced and sold is decreased. Second, customers are incentivized to return their used bottles to stores or redemption centers so that they can recoup the deposit fee. Deposit fees range from two to 15 cents per bottle, with the median fee being five cents per bottle. In all of these states, return rates for bottles covered under this bill were greater than 50%, according to the most recently available data.

E-waste laws offer another approach to recycling. As of March 2017, some 23 states had electronic take-back recycling laws on the books. These laws allow consumers to return desktop computers, laptops, televisions, printers, monitors, and other similar small-scale electronic devices free of charge. Common goals for these programs are non-binding recycling targets, often between 60%-80% between one and three years after implementation. The most expansive of these laws require manufacturers to pay for collection, transportation, and recycling of these products and ban these manufacturers from landfills, incinerating, or otherwise disposing of the collected products. Indiana, for example, requires manufacturers to pay for recycling from households, schools, and businesses with fewer than 100 employees. Manufacturers cover this cost based on their in-state market share. Indiana’s requirements are enforced through reporting requirements, mandatory yearly recycling targets, fines for noncompliance, and disposal bans, which ensure products are actually recycled. In contrast, the laws of many states operate on an almost voluntary basis. Missouri, for example, requires manufacturers to pay for recycling but does not mandate they provide any level of service (pick-up and/or drop-off times and locations, minimum or maximum one-time product deposits, and so on), meet any recycling goals, or suffer any consequences for noncompliance.

State e-waste laws in many instances represent a less rigorous instance of EPR schemes. According to the Product Stewardship Institute, some 36 states in the United States now have some form of EPR laws on the books. These laws apply on a product-by-product basis to batteries, carpets, electronics, fluorescent lighting, mattresses, mercury thermostats, paint, pesticide containers, pharmaceuticals, and appliances containing refrigerants. The general purpose of all of these laws is to make producers responsible for collecting and then responsibly disposing of, recycling, or reusing their products.

For almost a decade, advocates for EPR have promoted comprehensive or “framework” approaches that could be applied to multiple products. Such approaches “call on

42. Container Recycling Institute, supra note 40.
44. Id.
45. Id.
producers to take responsibility for designing, managing, and financing stewardship programs; government to set performance goals and ensure accountability; and consumers to return the products they no longer want to retail stores and other designated takeback locations. In the United States, only Maine has enacted a framework law, though it does not quite adhere to this more expansive vision. Nonetheless, there is no question that EPR laws have become a fixture at the state and local levels, and that they have a significant role to play in advancing a circular economy model.

c. Managing Food Scraps

Food scraps that are allowed to go to waste remain a significant source of GHG emissions, both in their upstream production and in their decomposition in landfills. Indeed, the problem of food scraps, both in terms of GHG emissions and waste management, is enormous. According to EPA, more than 38 million tons of food waste was generated in the United States in 2014, with only 5.1% diverted from landfills and incinerators for composting. The non-composted food waste is likely the largest single contributor to the nation’s everyday trash load, constituting an estimated 21.6% of discarded municipal solid waste. While there are multiple potential uses of repurposed food, here, the focus is on the diversion of food scraps from commercial and residential sources away from landfills and towards composting facilities. According to EPA, the total diversion of food scraps could result in the reduction of GHG emissions by 20 million metric tons CO₂/year.

A number of states—Connecticut, Massachusetts, Rhode Island, and Vermont—and several large cities—New York City, Austin, and San Francisco—have enacted food scrap recovery rules. These regulations generally regulate large-scale food scrap generators (criteria for defining regulated entities vary) and require that they sort and compost on-site or else contract with an appropriate composting facility or service provider. Vermont has banned all food scraps from the state’s landfill, with the ban becoming fully phased in by 2020. San Francisco requires all city residents to separate food scraps for municipal collection and composting. The purpose of these regulations is primarily to save space in landfills by reducing overall food waste and by reducing the amount of food waste that ever reaches landfills. Still, there is a climate benefit, and it represents another approach to the circular economy.

d. Industrial Solid Waste

The federal Resource Conservation and Recovery Act (RCRA) has detailed requirements for the management of hazardous waste, and less detailed requirements for the management of solid waste that is not legally hazardous. While municipal solid waste gets the bulk of public attention, another category of solid waste—industrial solid waste—is a larger category of waste than is widely recognized. EPA relies on states to “play a lead role” in enforcing its regulations for solid waste. Under RCRA, states also may adopt more stringent regulations than the federal requirements. Pennsylvania has developed and enacted comprehensive regulations regulating industrial solid waste, or what it calls residual waste. Residual waste is defined as waste “resulting from industrial, mining and agricultural operations and sludge from an industrial, mining or agricultural water supply treatment facility, wastewater treatment facility or air pollution control facility,” with certain exceptions. Pennsylvania’s regulations have stringent requirements for incineration and landfilling, and require extensive reporting of residual waste production and disposal. But they also incentivize the beneficial use of residual waste by providing an easier permitting process for these uses. Of the more than 900 residual waste facilities in the state, 768 either directly use the waste beneficially or process the waste so that it can subsequently be used beneficially. According to one study, residual waste
management in Pennsylvania can be credited with avoiding 0.9 million metric tons of CO₂e in 2004.\textsuperscript{64}

\textbf{B. Research and Development: Materials Innovation}

One of the key components of the circular economy concept is the invention and deployment of new materials and new ways of utilizing (or reutilizing) existing materials to reduce waste, including the waste of materials’ and products’ embedded GHG emissions. This is an area in which comparative analysis of GHG emissions is not yet available, but that represents a necessary element in considering long-term solutions to the problem posed by the extraction-based, disposal-oriented linear economy. Three examples follow.

\textit{Wheat straw}: Wheat straw, sometimes referred to as straw waste, is made up of the biological material left on an agricultural field after wheat is harvested. Some of this leftover material becomes straw used on-site (for animal feed or soil stability) but much of the material is either burned or disposed of as waste. Several companies (including Dell, Staples, the packaging materials manufacturer Npulp, and the makers of Kleenex) are harvesting this material as an alternate paper source.\textsuperscript{65} The wheat straw is collected, pulped, and mixed with new and recycled paper pulp to create products as diverse as tissue paper, toilet paper, cardboard boxes, and cardboard packaging. Harvesting of wheat straw reduces the destruction of virgin timber forests, eliminates the GHG emissions that would normally arise from burning of wheat straw, and reduces the amount of methane-creating biowaste reaching local landfills. Dell, one of the many corporations embracing wheat straw as a cheaper and greener paper source, claims that processing of wheat straw uses 40% less energy and 90% less water than traditional paper processing.\textsuperscript{66} Wheat straw has the added bonus of being readily available (it is produced after nearly every harvest), it is cheap (as farmers currently treat it as a waste product), and the amount of time it takes to grow a new crop is incredibly low (compared to the amount of time needed to plant and grow trees or other live biomass normally utilized to create paper products).

\textit{Cellulosic ethanol}: Liquid biofuels have the potential to reduce fossil fuel combustion and GHG emissions in the transportation industry. Ethanol is the primary biofuel used in these efforts. Ethanol is primarily produced through conversion of corn or sugar-based crops into liquid fuel.\textsuperscript{67} Creating ethanol from live crop harvesting raises both environmental concerns (growing crops uses fossil fuels, pesticides, fertilizer, and water, and converting these crops into ethanol and burning them in a mixture with gasoline still creates GHG emissions) and social justice concerns (as a greater portion of available agricultural land is used to grow corn for ethanol, less land is available for food crops). Creating ethanol from agricultural waste (cellulosic ethanol) limits many of the concerns related to traditional ethanol production while retaining the primary goal of reducing fossil fuel emissions through the implementation of biofuels. (Bioenergy feedstocks are discussed in Chapter 25.)

\textit{Mushrooms}: Mushrooms can be converted into plastic-like materials and are an emerging bio-alternative to plastic and polystyrene packaging sources. The primary production occurs in the dark and uses agricultural waste as an energy source for the mushrooms’ growth. Mushroom packaging takes less than two weeks to shape and grow and uses less than 10% of the energy needed to produce similar plastic products.\textsuperscript{68} Mushroom packaging is also compostable when placed in a normal residential compost pile or a commercial composting facility.

\textbf{C. Corporate Governance}

As noted above, the circular economy has been embraced by powerful actors in the private sector, including the U.S. Chamber of Commerce and a number of Fortune 500 companies.\textsuperscript{69} A number of companies have tied circular economy commitments to GHG emissions reductions; others promote links to energy efficiency improvements, energy savings, reduced fossil fuel consumption, or reduced waste. There is no one-size-fits-all approach, or set of metrics or indicators. The following case studies illustrate how corporate governance may prove critical to circular economy innovation and implementation.

\textit{Dell Inc.:} Dell has undertaken a number of initiatives to “close the loop” and realize the potential of a circular economy approach.\textsuperscript{70} In manufacturing new products, Dell uses at least 10% post-consumer closed-loop recycled content. Dell also collects consumer e-waste of any brand

\textsuperscript{64} M.J. Eckelman & M.R. Chertow, Quantiying Life-cycle Environmental Benefits From the Reuse of Industrial Materials in Pennsylvania, 43 Envl. Sci. & Tech. 2550 (2009).


\textsuperscript{66} U.S. CHAMBER OF COMMERCE FOUNDATION, supra note 6, at 18.

\textsuperscript{67} Martin Hirschnit-Gabres & Jorrit Gosen, Producing Bio-ethanol From Residues and Wastes (Recreate, Policy Brief No. 2, 2015).


\textsuperscript{69} U.S. CHAMBER OF COMMERCE FOUNDATION, supra note 6.

\textsuperscript{70} Id. at 18.
through its Dell Reconnect program; the company then sorts, breaks down, and sends the component part plastic to its factories for reuse in future Dell products. According to Dell, reclaimed and recycled plastic creates an estimated 11% fewer carbon emissions.71 Dell also has a goal to reduce packaging waste and has looked to new, biodegradable materials to achieve this goal, including wheat straw, bamboo, and mushroom-based cushioning.

_Hewlett Packard (HP):_ HP focuses extensively on both collecting used ink cartridges for recycling and on creating new ink cartridges from recycled material. According to the company, 75% of new ink cartridges use recycled plastics (the plastic comes from both returned ink cartridges and other collected consumer recycled plastic).72 This effort has reduced HP’s energy consumption by 54%, fossil fuel consumption by 54%, and water usage by 75%, with correlating GHG emissions reductions.73 It is unclear what percentage of ink cartridges are returned from individual customers, but HP does have a smart printing service that automates this exchange process for larger customers. Smart printers alert HP when they are low on ink, which triggers HP to send a new ink cartridge and an accompanying prepaid package that the customer can use to return the used ink cartridge.

_Royal Philips:_ Philips has started to create a “performance economy” in select lighting and healthcare scenarios, shifting away from selling products to selling services.74 For example, through the company’s “pay-per-lux” program,75 Philips retains ownership of its lighting products while customers simply pay for the lighting they need. This system allows Philips to maintain ownership of their products, increase its ability to replace and recycle outdated technology, and continue receiving payment throughout the life of the project rather than receiving the traditional up-front investment. Consumers benefit in the short term by avoiding the large initial cost of lighting infrastructure and in the long term by delegating maintenance and upgrading services to Philips, the owner and operator of the lighting system. According to Philips, energy savings are estimated to be between 50%-70% as compared with the traditional scenario.76 Philips employs similarly styled health equipment as a service model for its healthcare business, selling the service of new, large healthcare equipment, such as MRI machines, to hospitals rather than the technology itself. At the end of the products’ initial life cycle, Philips reclams and refurbishes the machines and eventually resells or rents them to hospitals looking to save money on high-functioning but used machinery.

_General Motors (GM):_ GM is pursuing its circular economy efforts by focusing on internal efficiency and zero-waste production at its own facilities. GM claims that more than 100 facilities have achieved this zero-waste goal.77 Zero-waste facilities reuse, recycle, and sell all of their waste, sending zero waste to landfills. Plastic, metal, and wood waste is reused or recycled. GM's electronic byproducts tracking system (along with their willingness to make a $10/ton of waste initial program investment) allowed the company to make its zero-waste program a reality.78

_Caterpillar:_ This manufacturer of large nonroad equipment employs a type of product-as-a-service model with some of its engines and products. These products are designed to be easily remanufacturable. Rather than being disassembled and recycled, certain parts of returned products (like engines and in some cases larger machines) can simply be removed and replaced, leaving the main product’s ability to function unaffected. Caterpillar sells these remanufactured products at a discounted rate with, essentially, a deposit fee. If customers return the product before failure, and thus in time for remanufacturing, they retain their deposit. Caterpillar has seen 94% compliance with this program, which has allowed continual refurbishing and resale of products.79

### IV. Legal Pathways to a Circular Economy in the United States

In the absence of federal legislation, the legal pathways to a circular economy in the United States will inevitably be more fragmented and variable than in Japan, China, or the EU. Simply put, there is no overarching federal legislation that addresses the materials management issues that must be addressed to achieve a circular economy and the GHG emissions reductions a circular economy would presumably entail; there is not even federal legislation that addresses the more straightforward recycling efforts that EPA has projected could reduce national GHG emissions by 670 million metric tons CO₂e/year.80 This is in part a function of the long-held view that “waste disposal [is] a
typical and traditional concern of local government.” Indeed, as previously noted, under RCRA, nonhazardous solid waste management, including recycling, is primarily the responsibility of state and local governments; the federal government is there to set minimum standards and provide support for state and local efforts.

Of course, new federal legislation would be one mechanism through which to achieve these goals. Scaling up from the state and local experimentation described above, Congress could pass legislation that: (1) bans the use of certain GHG-intensive materials and products; (2) sets forth minimum recycled content requirements for a wide range of materials and products; (3) establishes EPR for a wide range of products; (4) establishes life-cycle assessment and disclosure requirements for a wide range of materials and products; (5) establishes minimum state recycling rates and food scrap diversion rates; (6) establishes procurement requirements for the federal government consistent with circular economy and deep decarbonization goals; and (7) funds research and development into alternative biomaterials that can substitute for plastics. Such an effort would be economically justified: the jobs, revenue, and tax generation benefits of reuse and recycling of materials and products are well established.

Without congressional action, however, there is little regulatory space in which the federal government can operate in most of these areas (no legislation would necessarily be required for recommendations 6 and 7). Under the Obama Administration, EPA did a good deal to advance the effort through setting goals, public reporting, and developing information and methodologies. But the more feasible legal pathways to a circular economy involve regulatory interventions at the state and local levels; shifts in the nature of retailer-consumer transactions driven by EPR regimes and/or voluntary corporate initiatives; government procurement policies; incentives and financial support for cutting-edge research and development; and corporate governance. In addition, any viable legal pathway will also have to account for environmental and public health risks posed by the circular economy. These approaches cannot match the impact of a fully nationalized circular economy regime, but they can nonetheless play a complementary role.

### A. Regulatory Interventions at the Federal, State, and/or Local Level

As described above in Section III.A, state and local governments are already experimenting with regulatory approaches that address the waste problems posed by products, packaging, food scraps, and industrial solid waste. These efforts include local materials and product bans, fees, and recycling requirements; state recycling and extended producer liability laws; requirements and programs for managing food scraps; and industrial solid waste regulations. These approaches should be replicated in other jurisdictions to further their impact. In addition, they could be extended to a broader range of materials, products, and waste categories, including construction and demolition debris from the building sector. (See Chapter 10 (New Buildings).) They could also adopt more ambitious goals (e.g., zero waste), intermediate targets and timelines for achieving these more ambitious goals, and means of achieving them.

In addition to the existing approaches described in Section III and recommended immediately above, there are three other interrelated regulatory interventions that could be undertaken at multiple scales of government—from the federal to the local—to support a transition in materials and solid waste management towards a circular economy: life-cycle assessment and disclosure requirements, eco-labeling, and accounting for GHG emissions reductions achieved in this sector in emerging carbon markets.

Life-cycle assessment and disclosure requirements imposed by state legislatures might pertain to the broad sustainability of a product, or more specifically to its carbon footprint, and may inform decisionmaking by both government and private consumers. In addition, required disclosures may be administrative in nature, or more consumer-oriented, depending on whether one is looking at life-cycle assessment as a part of the regulatory process or as a way to inform product labels. In the United States, there are limited examples of life-cycle assessment and disclosure, geared towards either sustainability writ large or climate change in particular, in the administrative context. EPA is required to perform life-cycle analysis to create regulatory standards for renewable fuels under the Energy Independence and Security Act of 2007. Similarly, the state of California conducts a life-cycle analysis of GHGs for transportation fuels. In a separate context, in assessing the safety of food packaging materials under the Federal Food, Drug, and Cosmetic Act, the U.S. Food and Drug Administration conducts an assessment pursuant to the National Environmental Policy Act (NEPA) that includes an assessment of the environmental impact.

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stems from the packaging material’s use and disposal, including its recycling impact. In addition, in November 2016, the federal government amended the Federal Acquisition Regulation to “create an annual representation within the System for Award Management for vendors to indicate if and where they publicly disclose greenhouse gas emissions and greenhouse gas reduction goals or targets.”

Similarly, in May 2015, EPA amended the EPA Acquisition Regulation to include food scrap diversion as an element in assigning preferences to potential venues and contractors for EPA-sponsored meetings and conferences. These examples indicate potential areas for further legal action to enhance life-cycle assessment of materials’ and products’ carbon footprints: new federal or state legislation that mandates such assessment and disclosure, environmental review under NEPA and its state analogs, and government procurement policies at all levels can be leveraged to improve information and thus, potentially, influence the behavior of government agencies and regulated entities. (See Chapter 3.)

Product labeling may also help facilitate a transition to the circular economy. Eco-labeling, of course, is nothing new. Indeed, a 2009 survey identified about 600 labels in use around the world that communicate that various products satisfy one or another standard of being “eco-friendly,” including more than 80 on products sold in the United States. While there is no shortage of questions concerning the efficacy and reliability of many of these labels, it is also plausible that a uniform federal life-cycle label, or even variable state life-cycle labels, could prove effective.

The EU Ecolabel provides one template for what a “circular economy” label might look like. The Carbon Trust provides another in its newly launched Zero Waste to Landfill certification.

Finally, mature and emerging carbon markets developed by the federal government, subnational governments, and/or private actors, operating at the transnational, regional, and state scale, may be able to account for GHG emissions reductions achieved through materials and solid waste management. Integration will not always be easy. Carbon markets tend to allocate emissions allowances to individual emitting entities, and upstream and downstream emissions are typically excluded from the market (though emissions from purchased electricity may be included). Offsets are typically accounted for at the project level, and must meet stringent requirements—including that the GHG emissions reductions be permanent—that may disqualify some or many materials and solid waste management approaches. Nonetheless, the Climate Action Reserve in California has developed a protocol for obtaining credits for organic waste (food scrap) diversion in voluntary markets. And the Clean Development Mechanism to the Kyoto Protocol includes a methodology for obtaining offset credits for “the recovery and recycling of materials in municipal solid waste (MSW) to process them into intermediate or finished products, displacing the production of virgin materials in dedicated facilities, thereby resulting in avoidance of energy use.”

B. Research and Development

The transition to a truly circular economy will require significant innovation and development in the design of products and the content of materials that make up the real economy. Design must be made to extend the lifetime of materials and products. And new materials, like those discussed in Section III.B above, must replace some of the carbon-intensive materials that currently dominate. Funding for this large-scale research and development project will likely derive primarily from the private sector, as companies seek to profit from emerging demand, but federal and state governments clearly have a role to play. For example, Congress could increase funding for biomaterials research at the Division of Materials Research at the National Science Foundation. State and local governments could also give tax breaks and other incentives to new materials companies seeking to enter the market.

C. Corporate Governance

As discussed in Section III.C above, a number of corporations have adopted the mantra of the circular economy, stemming from the packaging material’s use and disposal, including its recycling impact. In addition, in November 2016, the federal government amended the Federal Acquisition Regulation to “create an annual representation within the System for Award Management for vendors to indicate if and where they publicly disclose greenhouse gas emissions and greenhouse gas reduction goals or targets.” Similarly, in May 2015, EPA amended the EPA Acquisition Regulation to include food scrap diversion as an element in assigning preferences to potential venues and contractors for EPA-sponsored meetings and conferences. These examples indicate potential areas for further legal action to enhance life-cycle assessment of materials’ and products’ carbon footprints: new federal or state legislation that mandates such assessment and disclosure, environmental review under NEPA and its state analogs, and government procurement policies at all levels can be leveraged to improve information and thus, potentially, influence the behavior of government agencies and regulated entities. (See Chapter 3.)

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C. Corporate Governance

As discussed in Section III.C above, a number of corporations have adopted the mantra of the circular economy,
and tied GHG emissions reductions targets or broader sustainability goals to enactment of one or more closed-loop reforms. Companies perceive the economic efficiencies that may be achieved and the advantages of voluntary action in comparison with regulation, and undoubtedly appreciate the positive public perception that attaches to such sustainability efforts. Companies that operate at every stage of economic activity—from extraction to transportation to manufacture to retail to service—should consider mechanisms, including circular economy concepts, through which they can demonstrate leadership in materials and solid waste management and reduce the use and waste of embedded GHG emissions.

D. Managing Environmental Risks of Specific Materials

Circulating materials and products through iterative uses, especially where this requires deconstructing and reconstructing them, raises environmental risks that must be addressed on a material-by-material, product-by-product basis. This section briefly discusses some of the key risks of three particular materials—electronic waste, plastics, and nanomaterials—and how they should be addressed.

Electronic waste is made up of many different toxics, heavy metals, polychlorinated biphenyls (PCBs), and other carcinogenic or otherwise harmful chemicals. There are several strategies for managing e-waste, once it has been created. One strategy is to refurbish and reuse electronic products rather than breaking them into their component parts. This strategy limits the potential release of toxics, limits the amount of waste reaching landfills, and creates a longer life cycle for existing products. Another management strategy could be called safe recycling. Safe recycling of e-waste means breaking down and recapturing both the useful and dangerous byproducts contained within products. The useful materials can be reused while the toxics can be captured and safely disposed of. This strategy could be enhanced by designing electronic products for easy disassembly and repurposing, consistent with the basic precepts of the circular economy model. The final strategy for managing e-waste could be referred to as unsafe recycling or simply salvage. E-waste managed unsafely, often by impoverished people in nations that did not create the e-waste, creates immediate health risks as unsafe chemicals and fumes are inhaled directly by salvagers. This process also creates long-term risks when toxics leak into the environment, potentially polluting local water systems and ecological systems. The risks around e-waste can be dealt with through design requirements imposed by federal or state governments on electronic products that facilitate repurposing and recycling. These may also be addressed through state e-waste regulations. Unsafe recycling is not recommended, but may well be inevitable.

Recycling and repurposing plastic also carry risk. Many plastic products are not made of “pure” plastic. They may contain nanomaterials, sealants, dyes, and any other number of substances. Recycled plastic products, if not closely managed, will contain some portion of these “other” substances. If these substances are toxic, the newly minted recycled plastic products will also be toxic. Common flame retardants are an example of a toxic substance that can be released into the atmosphere and into recycled plastic products if facilities do not specifically manage against this hazard. New and existing regulations of plastic recycling facilities, promulgated by the federal government or states, can address the potential leakage of these materials.

Finally, the number of products containing nanomaterials has expanded dramatically in the past decade—from concrete, to batteries, to paints, and plastic bottles. As the name suggests, these materials are extremely small. When used in products, they are contained. But during recycling processes, they may be released into the environment directly or in wastewater as they escape through filters that are simply not fine enough to capture nanoparticles. Many nanoparticles are toxic or carcinogenic, which creates risks to humans and other animals that ingest or inhale loose particles. The amount of nanomaterial released during recycling processes and the effect of these particles is still unclear. Yet because of their toxicity and increased bioavailability (due to the small size and easy uptake of these particles), it seems likely that managing these particles will be an important part of waste management moving forward. Increased research on management of nanomaterials in the waste stream and eventual regulation by the federal government or states adopting best practices is necessary to adequately address this issue.

V. Conclusion

The circular economy, even understood in the fairly limited sense of applying primarily to materials management and industrial ecology, provides a potentially centripetal force through which to reconstitute and remobilize efforts to “reduce, reuse, and recycle.” The GHG emissions reductions to be achieved are difficult to separate out from other deep decarbonization efforts discussed in this volume, but the intuitive appeal is obvious: the less we create, the less we use, the less we waste, the less we emit. What is more, EPA has made some estimates of what enhanced recycling programs might achieve. A comprehensive approach that

assigns specific waste reduction responsibilities and targets to government and private actors for a full range of materials and products could be enacted through federal legislation. States and local governments can continue to innovate through their regulatory interventions. The federal, state, and local governments can all contribute through procurement policies and funding and incentivizing research and development. Private actors can assist by installing private governance regimes that reduce waste in every stage of their operation.