

A Systems Approach to Sustainable Materials Management

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Abbreviations and Acronyms

C&D	Construction & Demolition
EPA	Environmental Protection Agency
EPA ORD	Environmental Protection Agency Office of Research and Development
IRR	Integrated Resource Recovery
IWM	Integrated Waste Management
MSW	Municipal Solid Waste
OECD	Organisation for Economic Co-operation and Development
SHCRP	Sustainable and Healthy Communities Research Program
SMM	Sustainable Materials Management

Section 1: Introduction and Background

As part of its mission to “protect human health and to safeguard the natural environment—air, water and land—upon which life depends,” the U.S. Environmental Protection Agency (EPA) has a number of intersecting goals.¹ One goal that addresses multiple media and sources of environmental risk and benefits is EPA’s commitment to “Cleaning Up Communities and Advancing Sustainable Development.” This goal is accompanied by several agency-wide strategies, one of which aims to “expand support of community efforts to build healthy, sustainable, green neighborhoods” and reduce and prevent health risks.²

EPA’s Office of Research and Development’s (ORD’s) Sustainable and Healthy Communities Research Program (SHCRP) works to develop tools to support community-level policies that operationalize sustainability and achieve meaningful improvements in quality of life. SHCRP supports community efforts to integrate policies that address land use, building and infrastructure, transportation, and sustainable materials management (SMM). SHCRP’s SMM efforts focus on improving flows of materials and associated waste streams to improve economic and social conditions in urban communities while minimizing the ecological footprint of materials.

Traditionally, community-level decisions about materials have centered on minimizing the cost and environmental impacts of “end-of-pipe” waste management options for household and commercial wastes. Landfills, energy recovery facilities, and recycling have been the most common options considered. SMM aims to expand the thinking of communities to bring a systems approach to the way materials use and management can be addressed. An SMM approach expands beyond end-of-life impacts to consider the ecological, economic, and human health impacts associated with material supply chains, and to incorporate decisions about design, manufacture, and purchasing that can reduce impacts to communities during use and disposal phases of materials’ life cycles. SMM approaches often draw on principles of industrial ecology to promote waste reduction or elimination by reusing by-product materials as an input for other products or services, as well as by improving waste management.

This report presents SMM approaches that can be used and outlines how these practices can help increase sustainability of communities. The organization of this discussion centers on the triple value framework – a life-cycle view of materials focused on interactions between flows of materials, energy, water, and food in the economy, society, and environment – as the basis for building a community-level SMM strategy. The paper uses the triple value framework to identify and examine different SMM practices and outline the interrelationships that can drive the impacts of policies related to materials. This paper also evaluates the available data and modeling approaches to support place-based policy and decision-making, and identifies areas for future research and development to support the adaption of SMM in communities. The discussion is organized as follows:

¹ U.S. Environmental Protection Agency. Office of Research and Development. “Sustainable and Healthy Communities: Strategic Research Action Plan 2012-2016.” June 2012. Available at: <http://www2.epa.gov/sites/production/files/2014-06/documents/shc-strap.pdf>

² U.S. Environmental Protection Agency. “FY 2014-2018 EPA Strategic Plan.” April 10, 2014. Available at: http://www2.epa.gov/sites/production/files/2014-09/documents/epa_strategic_plan_fy14-18.pdf

- **Section 2: Sustainable Materials Management Principles** defines SMM in the SHCRP context and provides a brief overview of its global development. The section describes key opportunities and challenges affecting SMM implementation, and introduces the triple value framework for structuring SMM-related analysis.
- **Section 3: Material Flows and Common SMM Practices in the U.S.** characterizes national-level material flows and SMM opportunities in the U.S., and briefly describes the economic, social, and environmental impacts of common SMM practices. The section layers SMM practices into the triple value framework, and identifies important points of system intersection that can affect the success of SMM efforts.
- **Section 4: Strategies for SMM** outlines a four-step approach to SMM implementation that includes stakeholder interaction, analytic priorities, and potential opportunities for SHCRP to encourage the process.
- **Section 5: Conclusions and Recommendations** discusses next steps for SHCRP in promoting SMM for communities and designing tools to support the process of adopting SMM.

Section 2: Sustainable Materials Management Principles

This section presents a working definition of SMM, describes its development as a strategy for addressing waste and materials management, and provides a brief overview of the global practice of SMM. The section also outlines key opportunities and challenges that communities face in identifying and implementing SMM strategies, and notes several analytical approaches that support SMM program implementation.

2.1 Introduction to SMM

EPA defines SMM as an “approach to serving human needs by using/reusing resources most productively and sustainably throughout their life-cycles.”³ SMM aims to reframe decisions addressing waste to consider options that move beyond typical options for end-of-life management of materials, such as recycling, composting, energy recovery, and landfilling. SMM uses and expands on end-of-life strategies to consider the use and reuse of materials across the life-cycle, from extraction through manufacture, use, and disposal. The aim is to develop, use, and dispose of materials in a way that is both productive and sustainable. Ideally, SMM policies ensure that materials provide needed functions in a way that conserves resources, reduces waste, slows climate change, and minimizes the environmental impacts of the materials consumed across the communities where they are produced, used, and discarded. These practices also aim to be economically efficient and include less easily monetized community benefits, such as societal impacts and improved quality of life.

Integrated Waste Management, Integrated Resource Recovery, and SMM

Sustainable Materials Management (SMM) is one of several different approaches to increasing the sustainability of waste and materials management. Two other common strategies are integrated waste management (IWM) and integrated resource recovery (IRR).

IWM aims to reduce material use and recycle materials to minimize raw material extraction and reduce, recycle, and manage discarded materials in ways that most effectively protect human health and the environment. Like community-driven SMM efforts, this approach evaluates local needs and conditions, and then selects and combines the most appropriate waste management activities to satisfy these needs and conditions.

IRR efforts reflect the view, consistent with SMM, that “waste” of all types is, due to the materials it contains, a potentially valuable resource that can be used to provide raw materials, generate clean energy, grow food, supply water, and reduce greenhouse gas emissions. This approach incorporates broader principles of efficiency and reuse, low impact development, decentralized wastewater management, energy generation and nutrient recovery.

While both approaches embrace principles that are consistent with SMM, both focus more specifically on “waste” management options than SMM, which extends materials management options to consider impacts and management of materials across systems and at every point in the material life-cycle.

³ U.S. Environmental Protection Agency. “What is Sustainable Materials Management?” April 13, 2012. Available at: http://waste.supportportal.com/link/portal/23002/23023/Article/32995/What-is-Sustainable-Materials-Management?_ga=1.118638025.196330328.1411689832

SMM has its origins in global efforts to focus on materials management and sustainability. In this context, the definition of SMM used by the Organisation for Economic Co-operation and Development (OECD) embodies four main principles:⁴

- preserve natural capital;
- design and manage materials, products, and processes for safety and sustainability from a life-cycle perspective;
- use the full diversity of policy instruments to stimulate and reinforce sustainable economic, environmental, and social outcomes; and
- engage all parts of society to take active, ethically-based responsibility for achieving sustainable outcomes.

Balancing the multiple objectives of SMM can be difficult. The approach requires a full understanding of the critical interactions of material flows through the economy, society, and the environment; often these flows involve global movements of resources that are difficult to measure and track, and changes often rely on decentralized adjustments in the behavior of individuals. At both a national and a community level, common SMM strategies and objectives have centered on the following goals:⁵

- Decrease urban demand for material consumption
- Decrease resource intensity of products & services
- Use substitute materials with lower life-cycle impact
- Encourage local sourcing of materials & products
- Increase recycling rates for commodity materials
- Recover and reuse wasted or underutilized resources
- Assure proper disposal for unwanted solid wastes
- Create economic incentives for material efficiency

The SMM strategies that are best aligned to achieve these goals typically encompass a suite of integrated practices (e.g., recycling, take-back strategies, green design, and others) that are tailored to the social, economic, and environmental contexts in which they are implemented. Successful SMM efforts most often emerge from careful, broad interaction efforts between leadership and stakeholders that are supported by high-quality data and a range of economic and environmental analyses. SMM stands apart from other efforts in that it aims to provide a holistic view and manage materials across all sectors of society and all activities. This may require long-term thinking about both the impacts of human behavior, and the most effective ways to improve it.

⁴ These are principles for SMM recommended by OECD presented in: OECD. "Green Growth Policy Brief: Sustainable Materials Management." October 2012. Available at: http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

OECD documents were selected to provide an overview of the global SMM principles as OECD is an international organization focused on promoting policies that promotes the social, economic, and environmental well-being of people around the world. The Organisation for Economic Cooperation and Development (OECD) is composed of 34 countries member countries with interacting market economics and 70 non-member economics to promote economic growth, prosperity, and sustainability development.

⁵ These objectives are derived from the principles and framework presented in: Fiksel, J. "A Framework for Sustainable Materials Management." *Journal of the Minerals Metals & Materials Society*. 2006. 58 (8):15–22. Available at: http://www.eco-nomics.com/images/Framework_for_SMM.pdf Fiksel's triple-value framework has been selected as the organizing principle for this paper because it has been broadly used to EPA to frame community-related sustainability efforts.

2.2 The Global Practice of SMM

Globally, the effort to integrate SMM into policy has emerged over the past decade, as OECD, EPA, and other national governments have taken on efforts to promote sustainable materials use.⁶ As early as 2005 and 2008, OECD conducted workshops to explore the future development of SMM activities and policies within member countries and beyond. Among the workshop participants were representatives from EPA's Office of Policy and Office of Solid Waste and Emergency Response; these offices have assumed a leadership role in integrating SMM into U.S. policies.

According to the OECD, policy options explored in OECD SMM workshops and later implemented in participating countries have contributed to the recent 42 percent improvement throughout the OECD countries in "resource productivity," a metric that estimates the materials produced per unit of resources used.⁷ Examples of SMM programs, ranging from instituting recycling and reuse to waste prevention across the OECD member countries, have been summarized in a green policy brief distributed by OECD on SMM.⁸

Over the past decade, individual OECD countries have documented significant improvements from SMM policies. In Japan, which OECD considers one of the most resource-efficient economies, a set of SMM measures has helped to increase the reuse and recycling of materials by 41 percent from 2000 to 2008.⁹ Japan has now decreased its material intensity (the quantity of material used to produce a unit of goods), to 37 percent, which is below the OECD average in 2005.¹⁰

In the U.K., a 2009 investment of 23 billion GBP (British Pound) in SMM-related projects produced a savings of 18 billion GBP in less than one year from waste reduction efforts and materials management, with further savings of 33 billion GBP expected.¹¹ The majority of these savings (22 billion GBP) are again associated with waste reduction and materials management.¹² These national successes often reflect significant changes in operations at individual companies. For example, one U.K. clothing firm, which spends about 550 million EUR managing waste in its shoe manufacturing process, has been able to

⁶ A starting point to explore international SMM policies can be found here: U.S. Environmental Protection Agency. "Sustainable Materials Management – Sustainable Consumption and Production." Available at: <http://www.epa.gov/oswer/international/factsheets/200810-sustainable-consumption-and-production.htm#OC>

⁷ Participating countries involved in the recent 42 percent improvement in resource productivity included all OECD countries, excluding Chile, Czech Republic, Estonia, Hungary, Poland, Slovak Republic, Slovenia, and Israel. A comprehensive list of OECD member countries can be found here: <http://www.oecd.org/about/membersandpartners/list-oecd-member-countries.htm>

OECD. "Green Growth Policy Brief: Sustainable Materials Management." October 2012. Available at: http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

⁸ OECD. "Green Growth Policy Brief: Sustainable Materials Management." October 2012. Available at: http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

⁹ OECD. "Green Growth Policy Brief: Sustainable Materials Management." October 2012. Available at: http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

¹⁰ OECD. "Green Growth Policy Brief: Sustainable Materials Management." October 2012. Available at: http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

¹¹ OECD. "Green Growth Policy Brief: Sustainable Materials Management." October 2012. Available at: http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

¹² OECD. "Green Growth Policy Brief: Sustainable Materials Management." October 2012. Available at: http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

streamline production and reduce waste by as much as 67 percent, energy use by 37 percent and solvent use by 80 percent along its supply chain.¹³

OECD also calculates that SMM efforts to improve resource productivity have increased local economic activity, particularly in waste collection and treatment, pollution management and control, production of renewable energy, and production of secondary materials through recycling. For instance, in the E.U., these four areas provide nearly 3.5 million jobs in addition to the energy and materials produced, and employment in sectors emphasizing materials management and recovery is growing at an annual rate of more than eight percent.¹⁴ A recent study by Friends of the Earth estimates that across the E.U., 322,000 direct jobs could be created in recycling if recycling increased from 50 percent to 70 percent for key materials.¹⁵ When considering the indirect jobs from this increase in recycling, the total potential job creation could be about 550,000 in the E.U.¹⁶

In the U.S., a range of government, business, and community organizations have adopted and promoted SMM strategies. EPA's federal efforts focus on policy support and capacity building; the Agency assists stakeholders in efforts to redesign waste management to incorporate SMM. One effort focuses on federal government operations; EPA directs the Federal Green Challenge, a national program that challenges 402 federal agencies to lead in implementing SMM principles to reduce the federal government's environmental impact.¹⁷ Under the Federal Green Challenge, participants select at least two of six target areas – waste, electronics, purchasing, energy, water, or transportation – and commit to annual performance improvements of at least five percent from baseline performance in each target area using key metrics such as electricity, natural gas, and/or fuel oil consumed per year for the energy target area and tons of waste generated per year for the waste target area. As part of its response to the Federal Green Challenge, the U.S. Navy's Naval Station Great Lakes increased materials recycling by 114 percent, reflecting efforts to compost (an effort that diverted more than 300 tons of food scraps and landscape waste from landfills), reuse construction and demolition debris, and increase the convenience of recycling.¹⁸

In addition to the Federal Green Challenge, EPA is pursuing a range of SMM-related national programs and challenges, as summarized in Table 1.

¹³ OECD. "Green Growth Policy Brief: Sustainable Materials Management." October 2012. Available at: http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

¹⁴ OECD. "Green Growth Policy Brief: Sustainable Materials Management." October 2012. Available at: http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

¹⁵ OECD. "Green Growth Policy Brief: Sustainable Materials Management." October 2012. Available at: http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

¹⁶ OECD. "Green Growth Policy Brief: Sustainable Materials Management." October 2012. Available at: http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

¹⁷ U.S. Environmental Protection Agency. "Federal Green Challenge – Current Participants." Available at: <http://www.epa.gov/fgc/participants.html>

¹⁸ U.S. Environmental Protection Agency. "Federal Green Challenge – Waste." February 2014. Available at: <http://www.epa.gov/fgc/waste.html>

Table 1. Examples of EPA’s national SMM efforts

EPA Effort	Description
Focus: Food Recovery Challenge	Organizations and businesses can join the EPA food recovery challenge and set specific goals to prevent and reduce wasted food. By finding opportunities to purchase less, donate extra food and compost, participants save money, help communities, and protect the environment. More information available here: http://www.epa.gov/epawaste/conserve/smm/foodrecovery/index.htm
Focus: Electronics Challenge	EPA works with original equipment manufacturers and retailers to promote responsible electronics recycling. Participants in the challenge commit to increasing the collection of electronics and to sending 100 percent of collected electronics to certified third-party recyclers. More information available here: http://www.epa.gov/epawaste/conserve/smm/electronics/index.htm
Broad Support: Provide Sound Science and Information	EPA supports SMM discussions and decisions by stakeholders at all levels of government throughout the nation by offering critical information and methods that the public and stakeholders can use (e.g., data on waste generation and life-cycle assessment methods) to help design and measure the impacts of SMM efforts. More information available here: http://www.epa.gov/smm/basic.htm
Broad Support: Facilitate Discussion	EPA works continually to facilitate and advance the national dialogue on SMM by regularly convening with key SMM stakeholders to discuss how best to implement SMM practices in communities. More information available here: http://www.epa.gov/smm/basic.htm

2.3 SMM Opportunities and Challenges

Despite evidence of growing global interest in SMM, sustainable materials approaches are far from ubiquitous, in part because of the complexity of the systems and the limited authority of specific stakeholders. In the U.S., for example, local communities often make decisions about waste management and materials policy, and are therefore critical stakeholders in adopting SMM, but often they have limited resources to develop and implement systems-level solutions. Opportunities to move waste management practices toward SMM are often linked to cycles of existing waste management contracts and infrastructure; a key challenge for EPA and others in encouraging SMM, therefore, is ensuring that communities have access to information and tools that help them readily evaluate SMM options when opportunities to implement them arise.

In addition to waste management policies and contracts affecting materials use (e.g., ordinances related to plastic bags and other products), community-level decisions about infrastructure, buildings, transportation, and land use can have important materials implications. By integrating SMM principles into decisions beyond “waste” and into other policy areas (e.g., infrastructure, land and water use, energy, and transportation), communities can often reduce costs, energy consumption, resource (e.g., water) consumption, and other impacts (e.g., traffic disruption related to movement of materials, loss of open space) while promoting economic development. In parallel with its SMM efforts, SHCRP is exploring opportunities for communities to improve the sustainability of three distinct areas: buildings/ infrastructure, transportation, and land use. To illustrate the relationships and impacts across these key areas, Table 2 outlines community-level SMM decisions; specific intersections with

infrastructure/buildings, transportation, and land use; and economic, social, and environmental impacts. While this paper centers on materials policies, the success of many SMM efforts may be driven in part by the extent to which policies intersect with other sustainability efforts.

While SMM policies, by definition, represent opportunities to improve economic efficiency and environmental quality, implementation can be difficult, particularly when authority to make policy decisions, resources to implement change, and access to information that can inform complex decisions are not aligned. Challenges to SMM implementation tend to fall into four general categories:

- **Financial barriers:** Some SMM policies, particularly those involving infrastructure investments, can be costly to implement, and benefits of improved materials management may be delayed, difficult to measure, or may accrue to different sectors and populations than those who incur implementation costs;
- **Limited coordination and authority:** To be effective, some SMM policy decisions (e.g., product takeback or regional waste facility options) require coordination across multiple communities, stakeholders, or levels of government; coordination and consensus can be difficult to achieve;
- **Timing challenges:** SMM policies can involve changes in long-term waste management contracts and facilities with planning horizons that do not align with policy options. In addition, SMM policies may require several years to realize benefits or cost savings, and may be difficult to justify in contexts driven by revenue or “payback” objectives;
- **Limited local benefits:** SMM policies often accrue benefits across materials’ life-cycle and large geographic scales, but only a portion of these benefits accrue to the community or stakeholder implementing the policy; this can reduce the attractiveness of SMM options to community decision-makers.

A critical step in addressing these challenges is making information and tools available so that communities can readily incorporate SMM options into their policy planning. In particular, tools that allow communities to identify and assess tradeoffs and benefits associated with SMM strategies, and compare these with more traditional waste management practices, can help communities pursue SMM practices that are most beneficial and feasible within specific community characteristics and resource constraints. A key component of SHCRP’s SMM strategy is developing and providing these tools.

Table 2. Intersection of SMM and other SHCRP sectors (land use, built infrastructure, and transportation) at the community level.

Sector Intersecting with Materials Management	Intersection at Community Level	Examples of SMM Strategies	Impacts
Transportation	<p>SMM can affect demand for local and long-distance transport of finished and raw materials and wastes</p> <p>Materials and practices related to transportation infrastructure may be affected</p>	<p>“End of pipe” (waste) options (e.g., recycling)</p> <p>Source reduction (e.g., material bans)</p> <p>Green remediation</p>	<p>Economic: may affect jobs for local material processing and transportation of wastes, may affect wear on infrastructure</p> <p>Social: may change traffic patterns and have benefits associated with avoided traffic impacts</p> <p>Environmental: may affect GHG, criteria pollutant, and air toxics emissions; water quality; and</p>

Sector Intersecting with Materials Management	Intersection at Community Level	Examples of SMM Strategies	Impacts
			open space associated with transportation and its infrastructure
Infrastructure/buildings	SMM can affect materials used in buildings and infrastructure Can affect building operations	“End of pipe” (waste) options (e.g., recycling) Source reduction (e.g., material bans, reusing recycled building materials for new construction) Green design	Economic: may affect cost of construction and operations, including energy use, property values and taxes Social: improved design and built environment can affect traffic, health, and quality of life Environmental: may affect GHGs and eco-system degradation, improve land use and design, traffic patterns, and reduce materials and resource use and impacts
Land use	SMM affects demand for land use for waste management (e.g., landfills) Encourages less-damaging remediation	“End of pipe” (waste) options (e.g., recycling, energy recovery, landfill mining) Source reduction (e.g., material bans) Green remediation	Economic: may affect property values and taxes Social: may affect open space opportunities, and associated human health and quality of life Environmental: may reduce land and water contamination, preserve open space; changes in practice can also result in energy or materials recovered from landfills.

2.4 SMM Analytical Framework: Triple Value Impacts

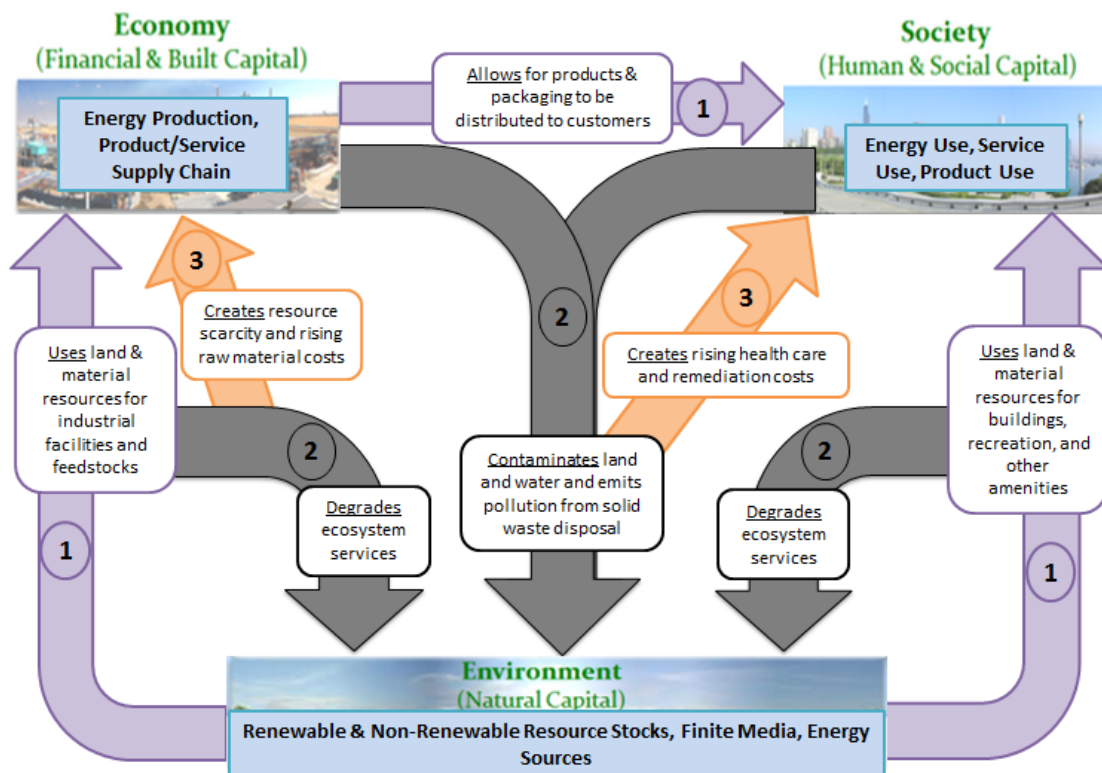
To identify effective materials management options, decision-makers must be able to identify and measure impact changes in materials use and related impacts across the economy, society, and the environment. EPA has used the “triple value framework” as a systems-level approach for defining and examining these complex options.¹⁹ The basis of the triple value framework is a comprehensive life-cycle view of materials. Specifically, the framework captures the relationships and interactions between stocks and flows of materials, energy, water, and food from extraction through disposal, and then considers and incorporates a broad range of environmental, social, and economic endpoints that can be affected by changes in the system.

This approach allows stakeholders to analyze and explore the system from many different perspectives, and can in some cases, reveal hidden synergies or conflicts. In the case of materials, the triple value framework considers not only the effects of disposal, but impacts associated with changes in other life-

¹⁹ J. Fiksel, R. Bruins, A. Gatchett, A. Gilliland, and M. ten Brink. “The Triple Value Model: A Systems Approach to Sustainable Solutions.” *Clean Technologies and Environmental Policy*: Volume 16, Issue 4 (2014), pp. 691-702.

cycle stages, including impacts on the environment (e.g., contribution to global climate change), economy (e.g., jobs created or eliminated), and society (e.g., changes in land use and traffic associated with different materials practices). The framework can be adapted and expanded to explore diverse policy options, and can support an assessment of policies that may address multiple goals of SMM and/or desired sustainability-related results, or may create tradeoffs across the system. Figure 1 provides a high-level, conceptual view of the triple value framework as it relates to material supplies (stocks), demand for, and use of (flows) across the economy, and notes significant (but not comprehensive) economic, social, and environmental effects of material use.

Figure 1. The economic, social, and environmental impacts of materials use in the triple value framework.



Product demand that drives the extraction and use of materials is reflected in purple (category 1) arrows. Materials discarded during extraction, manufacture, use, and at the end of product life are captured by gray arrows (category 2); these arrows reflect processes and flows where discarded materials (e.g., waste and emissions) may have a direct impact (either positive or negative) on the environment. Orange (category 3) arrows identify indirect impacts that result from materials management, such as human health-related costs. Because these flows and processes intersect, SMM strategies may affect all three categories of impacts to varying degrees. While the impacts of SMM strategies are indicated by changes in the “size” of arrows across diagrams, the effects on flows are not to scale; changes in stocks are likewise not pictured. (Adapted from: J. Fiksel, R. Bruins, A. Gatchett, A. Gilliland, and M. ten Brink. “The Triple Value Model: A Systems Approach to Sustainable Solutions.” *Clean Technologies and Environmental Policy*: Volume 16, Issue 4 (2014), pp. 691-702.)

Depicted graphically, the goal of SMM is simply to change the flows (arrows) in the systems, either by reducing the volumes and flows of materials (“making the arrows more slender”) or by eliminating or establishing new relationships (removing and adding new arrows).

The triple value framework provides a platform for describing and measuring the impacts and interactions of policies and activities that comprise SMM strategies. The remainder of this paper will use this model as a starting point for considering SMM impacts.

Section 3: Material Flows and Common SMM Practices in the U.S.

SMM is emerging globally as a component of sustainability-related policies at both national and local levels. SHCRP's priority is to improve the accessibility of SMM options and tools for communities in the U.S., and to enable local governments and stakeholders to adopt more sustainable policies and practices that promote environmental, economic, and social benefits.

The SMM practices and options likely to be most appropriate for communities are driven, in part, by the context of current U.S. materials management practices and the suite of emerging technologies. To characterize the scope of materials use and the potential impacts of SMM, this section briefly summarizes waste generation practices and patterns in the U.S. The section then describes several specific practices that represent common components of SMM strategies available to communities, and illustrates the types of impacts that these practices have on the dynamics and flows in the triple value framework.

3.1 U.S. Context: Material Flows

At its most basic, the triple value framework is a model of stocks and flows, illustrating how flows of materials and other “goods” and their associated impacts affect the “stocks” of the environment and the services it provides (natural capital), the economy and its capital, and society and its social capital (humans and social structures). SMM and other efforts to encourage sustainability aim to reduce damaging flows and impacts across the three types of capital, while maintaining needed services and goods.

The cumulative impacts of flows on the “stocks” of environmental, economic, and social capital are often measured as “footprints.” To identify the most effective materials management approaches in a community, an initial step is often understanding the “material footprint” of that community. Similar to a carbon footprint, a material footprint is an estimate of the total material generated in a system, and typically is based on a material flow analysis that captures impacts across the life-cycle, including extraction, manufacture, use, and disposal. National data on material flows in the U.S. provide an illustration of the elements and data that could be used to form a material footprint for a community, and also demonstrate the potential magnitude of impacts that could be addressed by broader adoption of SMM policies in the U.S.

This section provides an overview of the national materials flow based on high-level data that are readily available. Identifying high-quality local and even national-level data on specific material flows and interactions, however, remains a key challenge for communities, and forms a critical step in developing SMM strategies. This section briefly notes available data; Section 4 discusses available data and data sources in more detail.

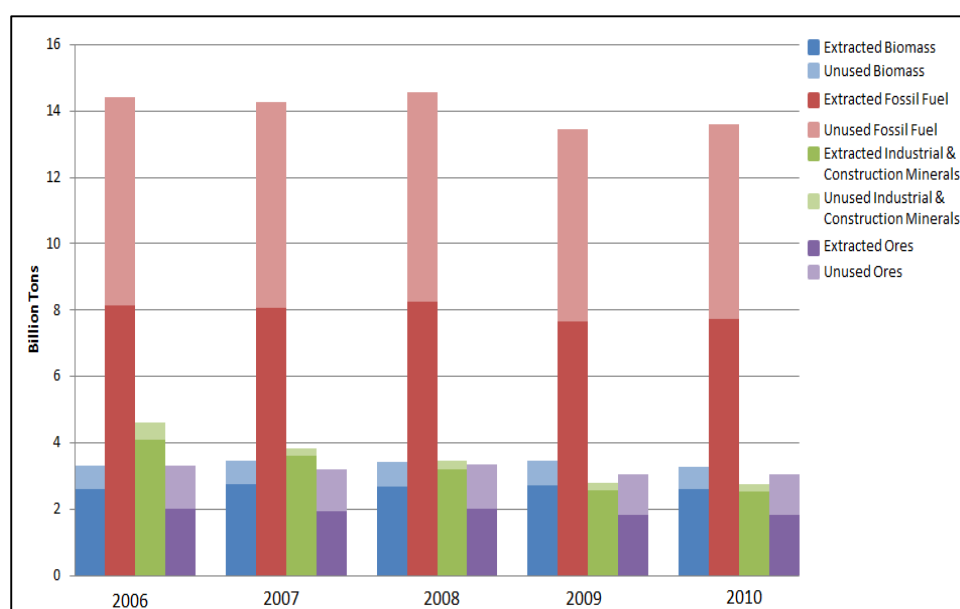
3.1.1 U.S. Material Flows - Extraction

All material resources are first extracted from the natural environment. Extraction often has significant impacts on the environment, and reduced extraction of raw materials is an integral part of SMM, aligning with the principle of preserving natural capital.

While many products and services used in the U.S. rely at least in part on non-U.S. materials extraction (and some U.S. raw materials are exported), domestic U.S. extraction illustrates the order of magnitude of extraction impacts. From 2006 to 2010, the U.S. extracted around 78.8 billion tons

of biomass (from the feed, food, and forestry industries), fossil fuel, industrial and construction minerals, and ores.²⁰ Of this, 53 percent of all materials went unused, and qualified as generated waste.²¹ Some of these materials can become part of community waste streams, particularly in communities with facilities that are involved in extraction, or in handling, processing, or managing extracted materials. In addition, land use in and near affected communities, and the wastes that remain on site at extraction sites, can become materials-related policy challenges. Figure 2 summarizes total U.S. materials extraction and unused extraction-related materials (e.g., waste), by categories of biomass, fossil fuels, industrial and construction minerals, and ores.²²

Figure 2. Total extraction and unused extraction of biomass, fossil fuels, industrial and construction minerals, and ores in the U.S.²³



3.1.2 U.S. Material Flows – Post-Extraction

After extraction, raw materials (both those extracted in the U.S. and imported raw materials) are processed and/or manufactured into products. From 2006 to 2010, the U.S. consumed roughly 40 billion tons of biomass, fossil fuel, industrial and construction minerals, and ores.²⁴ A portion of

²⁰ Materialflows.net. "Global Material Flow Database." March 2014. Available at: <http://www.materialflows.net/data/datadownload/>

²¹ Calculated from data found on: Materialflows.net. "Global Material Flow Database." March 2014. Available at: <http://www.materialflows.net/data/datadownload/>

²² For information on specific material categories considered in biomass, fossil fuel, ore, and industrial and construction extraction, see: http://www.materialflows.net/fileadmin/docs/materialflows.net/SERI_WU_MFA_technical_report_final_20140317.pdf

²³ Materialflows.net. "Global Material Flow Database." March 2014. Available at: <http://www.materialflows.net/data/datadownload/>

²⁴ Post-extraction is the total amount of materials used in the economy (used domestic extraction plus imports), minus the materials that are exported.

these materials become waste during production, and represent a source of discarded materials that must be managed. Aggregated estimates of total materials discarded during production can be periodically available for some sectors but quantities and types of waste vary significantly by sector and facility; community-level impacts are likely to be specific.

3.1.3 U.S. Material Flows – Post-Consumption

After post-extraction materials (i.e., products) are used by communities, residual post-consumption materials (often categorized as waste) are generated. Post-consumer materials can include materials that are designed to be discarded, such as packaging, as well as residuals from products that are consumed (e.g., food remnants) and products that have reached the end of their uses (e.g., electronics). At the national level, data on U.S. post-consumption materials is aggregated to reflect sources of the material, such as:

- municipal solid waste (including household and commercial waste),
- construction and demolition waste, and
- biosolids.

Municipal Solid Waste (MSW) is typically managed at a community-level. MSW, generally known as trash, consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries from residences, schools, hospitals, and businesses.²⁵ Generation of MSW is diffuse and collection and management of these materials often involves significant resources.

In recent decades, U.S. generation of MSW has increased steadily with population. From 2000 to 2012, EPA's report estimates that total MSW generation increased by eight percent, from 231.9 million tons to 251 million tons, an increase driven in part by population growth and in part by changes in purchasing patterns and changes in materials such as packaging.^{26,27} According to EPA, the increased rate of materials consumption reflected in the rate of MSW generation "has led to serious environmental effects such as habitat destruction, biodiversity loss, overly stressed fisheries, and desertification."²⁸ Since 2005, however, MSW generation has plateaued at around 250 million

Materialflows.net. "Global Material Flow Database." March 2014. Available at: <http://www.materialflows.net/data/datadownload/>

²⁵ U.S. Environmental Protection Agency. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012 and 2000." February 2014. Available at: http://www.epa.gov/solidwaste/nonhaz/municipal/pubs/2012_msw_fs.pdf

Sewage is not included in MSW.

²⁶ Specific materials included in MSW can be found in table 8 of this document: U.S. Environmental Protection Agency. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012 and 2000." February 2014. Available at: http://www.epa.gov/solidwaste/nonhaz/municipal/pubs/2012_msw_fs.pdf

²⁷ U.S. Environmental Protection Agency. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012 and 2000." February 2014. Available at: http://www.epa.gov/solidwaste/nonhaz/municipal/pubs/2012_msw_fs.pdf

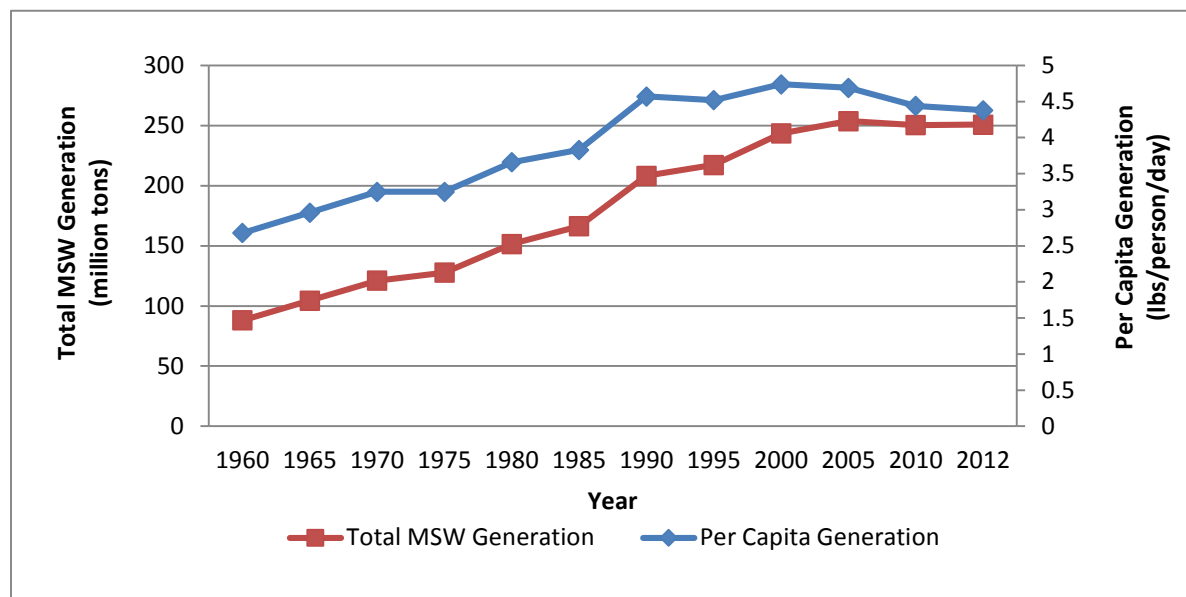
²⁸ U.S. Environmental Protection Agency. Office of Research and Development. "Materials Management: State of the Practice 2012." September 2012.

tons, which EPA notes coincides with an increase in recycling.²⁹ Figure 3 outlines MSW generated since 1960.³⁰

EPA's annual waste characterization report³¹ provides model-driven estimates of the national quantities of specific material in MSW, along with the percentages recycling, landfilled, and sent to energy recovery. Because most solid waste is managed at the community level, more specific detail on the content and recovery of specific materials is sometimes available for specific locations, but specific data collected depends on the structure of contracts for hauling, recycling, and disposing of wastes.

MSW is typically managed by a combination of landfilling, recycling, and other materials recovery (composting and energy recovery). A number of specific materials in MSW are recovered for recycling due to established secondary materials markets. Figure 3 provides summary information about MSW generation and recovery from EPA's 2012 waste characterization report.³²

Figure 3. Total U.S. MSW generation and per capita generation from 1960 to 2012



²⁹ U.S. Environmental Protection Agency. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012 and 2000." February 2014. Available at: http://www.epa.gov/solidwaste/nonhaz/municipal/pubs/2012_msw_fs.pdf

³⁰ U.S. Environmental Protection Agency. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012 and 2000." February 2014. Available at: http://www.epa.gov/solidwaste/nonhaz/municipal/pubs/2012_msw_fs.pdf

³¹ U.S. Environmental Protection Agency. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012 and 2000." February 2014. Available at: http://www.epa.gov/solidwaste/nonhaz/municipal/pubs/2012_msw_fs.pdf

³² U.S. Environmental Protection Agency. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012 and 2000." February 2014. Available at: http://www.epa.gov/solidwaste/nonhaz/municipal/pubs/2012_msw_fs.pdf

Table 3. Total 2012 U.S. MSW generated, recycled, and discarded by material

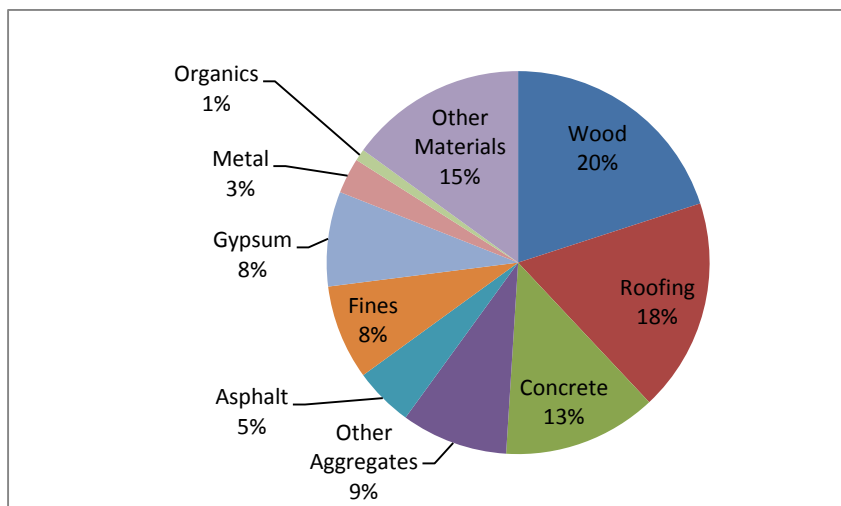
Material	Materials Generated as MSW (millions of tons)	Materials Recycled (millions of tons)	Materials Discarded in Landfills (millions of tons)
Paper and paperboard	68.62	44.36	24.26
Glass	11.57	3.20	8.37
Metals			
Steel	16.80	5.55	11.25
Aluminum	3.58	0.71	2.87
Other nonferrous metals	2.00	1.36	0.64
Total metals	22.38	7.62	14.76
Plastics	31.75	2.80	28.95
Rubber and leather	7.53	1.35	6.18
Textiles	14.33	2.25	12.08
Wood	15.82	2.41	13.41
Other materials	4.60	1.30	3.30
Total materials in products	176.60	65.29	111.31
Other wastes			
Food, other	36.43	1.74	34.69
Yard trimmings	33.96	19.59	14.37
Miscellaneous inorganic wastes	3.90	N/A	3.90
Total other wastes	74.29	21.33	52.96
Total municipal solid waste	250.89	86.62	164.27

Construction and demolition (C&D) waste is another set of materials that are typically managed at a community-level. C&D consists of unused materials and debris generated during the construction, renovation, and demolition of buildings, roads and bridges. C&D waste material flows represent a significant policy challenge for many communities because of their volume, and also because they are generated in unpredictable quantities that fluctuate over time with activities that relate to infrastructure and housing and periodically, destruction from natural disasters. Because C&D involves, by definition, built infrastructure, SMM policies that address C&D waste would ideally be linked to sustainability initiatives involving transportation, buildings, and in some cases, land use.

C&D materials consist primarily of concrete, wood (from buildings), asphalt (from roads and roofing shingles), gypsum (the main component of drywall), metals, bricks, glass, plastics, salvaged building components (doors, windows, and plumbing fixtures), and trees, stumps, earth, and rock from clearing sites. Though some C&D materials, such as road-related concrete and asphalt, are readily recycled, other materials are difficult to recover due to contamination and variability in generation and supply. EPA does not assemble national data on C&D waste, and data from other sources is

limited and sporadic. Therefore, data that reflect how C&D waste is changing over time is not available. One recent estimate suggests, however, that approximately 149 million tons of C&D waste was landfilled in C&D landfills, landfills that exclusively handle C&D waste, in 2011.³³ Figure 4 breaks down the composition of C&D materials landfilled:³⁴

Figure 4. Composition of C&D materials landfilled (after recycling)



Biosolids, the nutrient-rich organic materials that result from the treatment of sewage sludge, represent a third set of materials that are generally managed at the community-level. Biosolids management options for local governments include processing and using (or selling) biosolids as a fertilizer, incineration, or landfilling. EPA estimates that approximately 7.18 million dry tons of biosolids were produced in the U.S. in 2004.³⁵ While this material flow is not as large as other post-consumer materials, treatment of water, sewage, and the solids associated with both represents a significant focus – and cost – for communities.

3.2 Impacts of U.S. Materials Use

Historically, due to the relative abundance of land and the higher cost of other options, most residual materials in the U.S., including extraction, post-extraction, and post-consumption waste, have been landfilled.³⁶ Until the 1980s, most landfills were managed by local communities across the U.S. More recently, as technical requirements for landfill liners and other regulations have been implemented, land disposal of materials has been consolidated into larger regional and commercial facilities. According to EPA estimates, more than 1,100 MSW landfills currently operate across the

³³ U.S. Environmental Protection Agency. Office of Research and Development. "Multimedia Environmental Assessment of Existing Materials Management Approaches for Communities." September 2014.

³⁴ U.S. Environmental Protection Agency. Office of Research and Development. "Multimedia Environmental Assessment of Existing Materials Management Approaches for Communities." September 2014.

³⁵ King County. "Appendix B – Biosolids Use in the US and World." *Biosolids Recycling*. January 21, 2015. Available at: <http://www.kingcounty.gov/environment/wastewater/Biosolids/DocumentsLinks.aspx>

³⁶ Other methods of waste disposal do exist, such as ocean disposal and overseas shipping of waste. However, given this paper's focus on materials management of communities based in the U.S., this document will only go into detail on landfilling.

U.S., managing 4.5 billion tons of materials per year.³⁷ This contrasts with 2,283 landfills managing 6.9 billion tons in 1990.

Stricter regulation of landfills began after the 1970s, when the ecological and human health impacts of unregulated landfills emerged in communities across the country such as Love Canal, New York; these contamination incidents spurred the development of the Superfund law (CERCLA) to remediate sites and RCRA, which requires engineering and operational standards for open MSW landfills, including liners and leachate collection systems and capping requirements that reduce risks at newer facilities as older facilities close. More recently, systems for capturing methane gas, a potent greenhouse gas, from material decomposition have gained popularity, both as a strategy for recovering energy and as a method for addressing greenhouse gas emissions.

Even safely-operated landfills can have negative effects on communities due to impacts of traffic, odors and noise, and they may be viewed as an unattractive and perhaps uneconomical use of land when compared to other land use options. Finally, landfills can represent an inefficient use of resources, both in terms of land use and because some materials disposed in landfills have market value that could be recovered, and could offset additional virgin materials extraction and use.

Even as SMM practices and recycling demand increase, the demand for landfilling and its associated impacts are likely to grow as population increases, in part because existing infrastructure and land availability continues to make landfilling the least expensive waste management option in many places. Globally, increases in both population and standard of living will also likely increase demand for landfills. EPA projects “that between 2000 and 2050, the world population will grow 50 percent, global economic activity will grow 500 percent and global energy and materials use will grow 300 percent.”³⁸ The U.S. represents around one-third of the world’s current total material consumption, domestic population and economic growth will present U.S. communities with increasing materials use and management challenges.

In addition to disposal of post-consumer materials, some communities face detrimental impacts from resource extraction for materials use. While some of these impacts are directly associated with materials management (e.g., tailings piles), resource extraction can also affect water, energy, and food security, both in the local communities where it takes place and more broadly. Materials extraction and processing increase demand for, and scarcity of, water, energy, and land resources, and can come into direct conflict with other land use priorities such as agriculture. In the U.S., a majority (83 percent) of materials extraction is focused on finite mineral resources, including ores, fossil fuels, and industrial minerals.³⁹

While agriculture is not comparable to extraction of minerals in that the crops grown are, at least to some extent “renewable,” the impacts of agricultural practices can be complicated. One example of the complexity of the resource extraction system is biofuels production, which demands extensive water and land, and even energy, to ensure the production of feedstocks for energy.

³⁷ U.S. Environmental Protection Agency. “Landfill Methane Outreach Program – National and State Lists of Landfills and Energy Projects.” March 2015. Available here: <http://www.epa.gov/lmop/projects-candidates/index.html>

³⁸ U.S. Environmental Protection Agency. “Sustainable Materials Management: The Road Ahead.” June 2009. Available at: <http://www.epa.gov/smm/pdf/vision2.pdf>

³⁹ Calculated from data obtained from:

Materialflows.net. “Global Material Flow Database.” March 2014. Available at: <http://www.materialflows.net/data/datadownload/>

Overall, the economic and social impacts of managing waste can be significant for communities. According to U.S. Census data on municipal budgets, American communities on average spend more money on MSW management than on fire protection, parks and recreation, libraries or schoolbooks.⁴⁰ For instance, in 2011, New York City spent \$2.2 billion on sanitation of which more than \$300 million was spent on transporting its citizens' trash by train and truck to out-of-state landfills.⁴¹ SMM focuses on the extent that some of these materials can be diverted or eliminated from waste management systems, and save money while conserving resources.

Production and disposal of materials can also have negative social impacts on communities, particularly those near production and disposal sites. According to the 2010 U.S. census, 249 million people (roughly 81 percent of the U.S. population), live in urban communities.⁴² The concentration of people in urban centers presents specific challenges related to volumes of waste, and relative scarcity of land and options for management. Census data reveals that populations likely to live close to facilities that generate or manage waste are comprised of more minority, low income, and linguistically-isolated citizens, who are also less likely to have high school educations relative to the U.S. population as a whole. As a result of this proximity, low-income residents in urban communities may be subject to disproportionate exposures of hazardous substances at facilities that handle concentrated volumes of urban and production wastes.

In both the urban and broader U.S. context, community-based SMM approaches are designed to help identify opportunities to reduce or improve material management at all stages of the system, from extraction to consumption to disposal, by helping communities assess the broader environmental, economic, and social impacts that result from different processes.

3.3 Role of SMM Practices in Addressing Impacts of Materials Use

SMM aims to change the materials-related practices of the U.S. in a manner that reduces material extraction and consumption.

SMM Principles

SMM strategies operate through changes in design, use, disposal, and recovery, according to the four principles developed by OECD's workgroup on SMM and outlined in Section 2 (repeated here):

- Preserve natural capital;
- Design and manage materials, products and processes for safety and sustainability from a life-cycle perspective;
- Use the full diversity of policy instruments to stimulate and reinforce sustainable economic, environmental, and social outcomes; and
- Engage all parts of society to take active, ethically-based responsibility for achieving sustainable outcomes.

⁴⁰ Humes, Edward. "Grappling with a Garbage Glut." *Wall Street Journal*. April 18, 2012. Available at: <http://www.wsj.com/articles/SB10001424052702304444604577337702024537204>

⁴¹ Humes, Edward. "Grappling with a Garbage Glut." *Wall Street Journal*. April 18, 2012. Available at: <http://www.wsj.com/articles/SB10001424052702304444604577337702024537204>

⁴² U.S. Census Bureau. "Frequently Asked Questions - How many people reside in urban or rural areas for the 2010 Census? What percentage of the U.S. population is urban or rural?" Available at: <https://ask.census.gov/faq.php?id=5000&faqId=5971>

Existing SMM strategies are designed to consider a number of different system dynamics, but they typically employ one or a combination of several well-known practices that address different aspects of materials extraction, use, and disposal. SMM literature has identified seven practices that are either commonly used or emerging in the U.S. The remainder of this section focuses on the seven most commonly-discussed practices; these represent the suite of practices that collectively address all aspects of the materials system and also generally reflect well-documented technology and market options for communities.⁴³

- Materials Recovery and Recycling
- Energy Recovery
- Landfill Mining
- Product Take-Back
- Source Reduction
- Green Design
- Green Remediation

While they are often described interchangeably with SMM, these practices are not themselves synonymous with SMM. Outside of the SMM context, the practices may have significant benefits by one measure, but can also be designed in a way that is less beneficial by another measure. For example, a recycling program that targets a single material and uses an energy- and emission-intensive process that has negative impacts on the surrounding community is not consistent with an SMM strategy. SMM aims to avoid this type of tradeoff through system approaches that increase the net benefits while reducing the net negative impacts.

When applied in a context consistent with OECD's SMM principles and supporting SMM-related goals (e.g., decreasing resource intensity of products and services, or encouraging local sourcing of materials), these practices can help reduce material flows and mitigate negative impacts that current materials practices impose upon the economy, society, and environment.⁴⁴ The following section briefly describes each of these practices, and illustrates how it can contribute to improvements in the social, economic, and environmental systems captured in the triple value framework relative to the traditional waste management practice of landfilling.

3.3.1 Materials Recovery and Recycling

Post-consumer materials recovery and use as inputs into new processes and products (also known as recycling, which in this document also includes the composting of organic materials), is the most established and widespread of the common SMM practices. It is already an effective waste diversion option in the U.S.; in 2011, EPA reported more than 9,000 active U.S. curbside recycling programs.⁴⁵ Recycling programs involve collecting, sorting, and processing materials that would otherwise be

⁴³ These practices were identified as practices commonly cited in EPA and literature sources on SMM, including:

- U.S. Environmental Protection Agency. Office of Research and Development. "Materials Management: State of the Practice 2012." September 2012, and

- Fiksel, J. "A Framework for Sustainable Materials Management." *Journal of the Minerals Metals & Materials Society*. 58 (8):15–22. Available at: http://www.eco-nomics.com/images/Framework_for_SMM.pdf. These are not intended to be a comprehensive list of practices.

⁴⁴ Fiksel, J. "A Framework for Sustainable Materials Management." *Journal of the Minerals Metals & Materials Society*. 58 (8):15–22. Available at: http://www.eco-nomics.com/images/Framework_for_SMM.pdf.

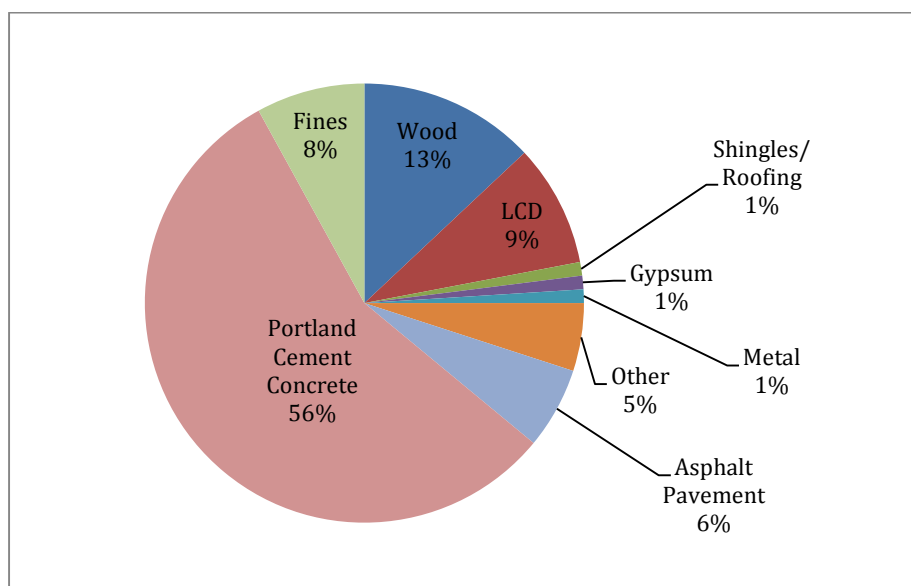
⁴⁵ U.S. Environmental Protection Agency. Office of Research and Development. "Materials Management: State of the Practice 2012." September 2012

landfilled. The recovered materials then enter secondary materials markets and become inputs to new products.

Recycling programs can differ widely across communities, both in the materials collected and in collection and sorting processes. Some communities have limited drop-off options for specific materials; others have single-stream curbside or broader wet-dry collection systems where residents must separate MSW into wet (e.g., organics such as food and yard waste, food wrappers, used tissues, and paper towels) and dry (e.g., recyclables such as bottles, cans and cardboard) categories. Indirectly related to recycling, more than 7,000 communities in the U.S., implement Pay-As-You-Throw (PAYT) programs that charge households by weight for non-recyclable MSW; because most programs charge less, or nothing, for recycling, this provides an economic incentive to recycle.⁴⁶ As of 2012, 34.5 percent of U.S. MSW (roughly 87 million tons) is recycled annually.⁴⁷

Though not tracked as well as MSW, recycling of C&D materials is also significant, particularly for road-related debris, where reuse of asphalt and concrete in re-laying roads is the most cost-effective approach to construction. Recent estimates suggest that of the approximate 149 million tons of C&D waste generated in 2011, 52 million tons were recycled.⁴⁸ Figure 5 breaks down the composition of C&D materials recycled:⁴⁹

Figure 5. Composition of C&D materials recycled



⁴⁶ U.S. Environmental Protection Agency. Office of Research and Development. "Materials Management: State of the Practice 2012." September 2012

⁴⁷ U.S. Environmental Protection Agency. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012." February 2014. Available at: http://www.epa.gov/solidwaste/nonhaz/municipal/pubs/2012_msw_fs.pdf

⁴⁸ U.S. Environmental Protection Agency. Office of Research and Development. "Multimedia Environmental Assessment of Existing Materials Management Approaches for Communities." September 2014.

⁴⁹ U.S. Environmental Protection Agency. Office of Research and Development. "Multimedia Environmental Assessment of Existing Materials Management Approaches for Communities." September 2014.

Biosolids, once recovered, are also “recycled” through application to soils to provide nutrients; recent estimates suggest that of the 7.18 million dry tons of biosolids produced in the U.S., 55 percent of biosolids were recycled and applied to soils for beneficial use.⁵⁰

If properly recovered, biosolids can be low in pollutants and rich in nutrients and organic matter, and can provide nutrients and conditioning to soils to improve fertility, reduce the need for inorganic fertilizers, promote crop growth, and decrease demand for inorganic fertilizers.⁵¹

3.3.2 Materials Recovery and Recycling in the Triple Value Framework

Recycling is a well-established practice and recycling technologies continue to evolve to better economically recover existing and new materials, such as nonmetallic components of circuit boards (roughly three percent of all electronic waste).⁵² Tailored blending technologies for mixed materials that are difficult to separate or have limited secondary markets can also produce durable products such as fences, sewer grates, and park benches.⁵³

As the technology evolves, recycling systems and networks are also expanding and increasingly incorporating practices from industrial ecology, which seeks to link organizations in a particular network through material flows, wherein by-product materials of one entity can be used as inputs for another.

Even as a singular practice, recycling can have substantial economic, social, and environmental benefits, both at the community level and globally. Most significantly, recovered materials reduce demand for virgin materials, avoiding the energy, water, land use, solid waste, and emissions associated with extraction. Other benefits of recycling include broader societal impacts, including reduced risk of resource scarcity, reduced raw material costs, positive health impacts, and decreased remediation costs. Recycling can achieve these benefits while improving local economic conditions by creating local jobs in recovery (extraction) of secondary materials.

Figure 6 illustrates recycling’s impacts within the triple value framework, including its effects on the flow of materials across the economy, environment, and society and its broader benefits. The system impacts of recycling are reflected conceptually in the changing size of certain flows (width of arrows in the diagram). Direct benefits can include decreases in end-of-life impacts, and a corresponding “new” source of materials (the green recycling arrow denoting recovered secondary materials) that offsets the demand for, and impacts related to, virgin raw materials. Demand for products and the material intensity of those products, however, is not affected.

⁵⁰ The recovery of biosolids for land use, land disposal, or incineration must comply with numerical limits for metals, pathogen reduction standards, site restriction, crop harvesting restrictions and monitoring, and other requirements.

King County. “Appendix B – Biosolids Use in the US and World.” *Biosolids Recycling*. January 21, 2015. Available at: <http://www.kingcounty.gov/environment/wastewater/Biosolids/DocumentsLinks.aspx>

⁵¹ King County. “Appendix B – Biosolids Use in the US and World.” *Biosolids Recycling*. January 21, 2015. Available at: <http://www.kingcounty.gov/environment/wastewater/Biosolids/DocumentsLinks.aspx>

⁵² Earth 911. “Back to the Future with New Recycling Technologies.” Available at: <http://www.earth911.com/eco-tech/trash-heading-back-to-the-future-with-new-recycling-technologies/>

⁵³ Earth 911. “Back to the Future with New Recycling Technologies.” Available at: <http://www.earth911.com/eco-tech/trash-heading-back-to-the-future-with-new-recycling-technologies/>

3.3.3 Energy Recovery

Some materials with a high organic content represent an economically efficient source of energy, either through combustion or through recovery of gas associated with decomposition. In 2012, EPA estimates that approximately 12 percent of national MSW, (or 29.3 million tons) was converted into energy.⁵⁴ Landfill gas can be converted into electricity, used directly as a fuel for local industries or specialized applications, or processed into pipeline-quality natural gas for distribution.

Approximately 600 landfills in the U.S. use landfill gas capture and energy conversion, utilizing methane and carbon dioxide released from decomposing organic matter in landfills as stocks for usable fuels.⁵⁵

A related technology, anaerobic digestion, uses enclosed systems and microorganisms to break down biodegradable material and create biogas. Most commercial anaerobic digestion systems in the U.S. are designed to accept manures and sludge with high organic content. Around 3,500 wastewater treatment plants (24 percent of wastewater treatment plants in the U.S.) and 190 commercial livestock farms currently have anaerobic digestion systems to supply power to their operations.^{56,57}

A third established technology for recovering the energy value of materials is combustion of MSW to drive steam turbines. While this technology is more prevalent in Europe, over 60 communities in the U.S. have commercial-scale waste-to-energy plants.⁵⁸ Newer combustion technologies such as plasma gasification are also under development in other countries and under consideration in the U.S.⁵⁹

⁵⁴ U.S. Environmental Protection Agency. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012." February 2014. Available at:

http://www.epa.gov/solidwaste/nonhaz/municipal/pubs/2012_msw_fs.pdf

⁵⁵ U.S. Environmental Protection Agency. Office of Research and Development. "Multimedia Environmental Assessment of Existing Materials Management Approaches for Communities." September 2014.

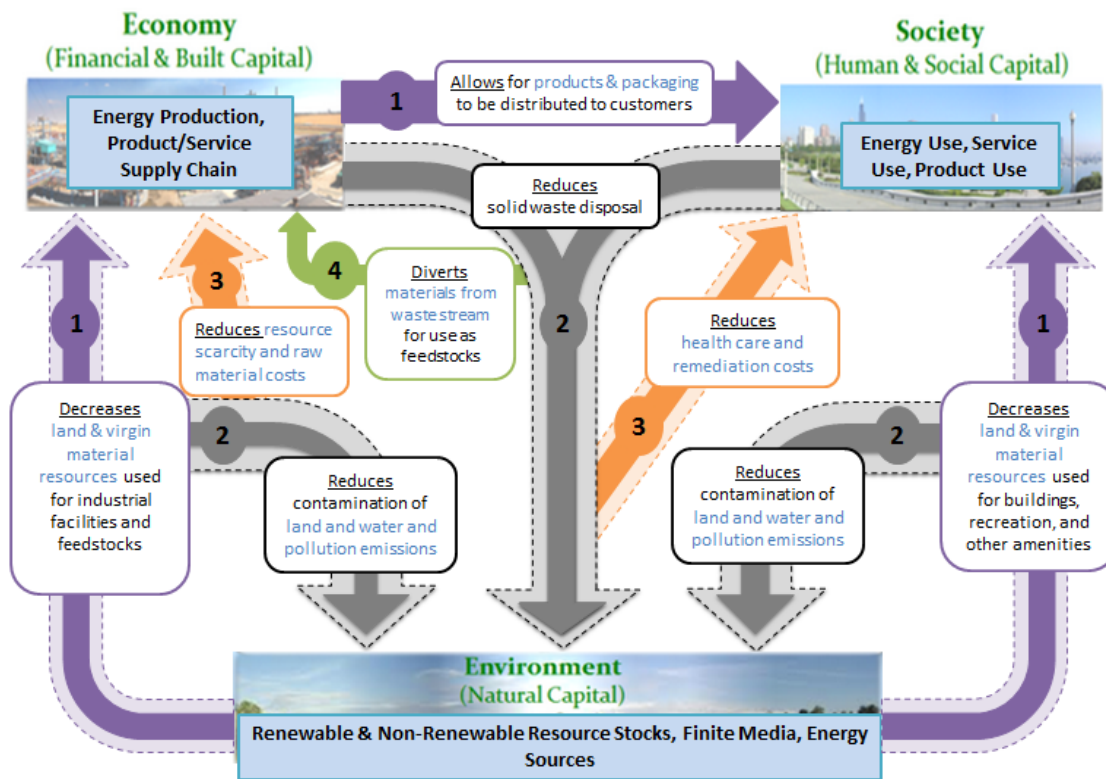
⁵⁶ U.S. Environmental Protection Agency. Office of Research and Development. "Multimedia Environmental Assessment of Existing Materials Management Approaches for Communities." September 2014.

⁵⁷ University of Michigan Center for Sustainable Systems. "U.S. Wastewater Treatment Factsheet." 2014. Available here: http://css.snre.umich.edu/css_doc/CSS04-14.pdf

⁵⁸ U.S. Environmental Protection Agency. Office of Research and Development. "Multimedia Environmental Assessment of Existing Materials Management Approaches for Communities." September 2014.

⁵⁹ Wolman, D. "High-Powered Plasma Turns Garbage into Gas." January 20, 2012. Available here: <http://www.wired.com/2012/01/ff-trashblaster/>

Figure 6. The economic, social, and environmental impacts of materials recovery and recycling in the triple value framework



Under recovery and recycling, materials are diverted from the waste stream to be used as feedstocks; this is represented by the green (category 4) arrow. Product demand stays constant while extraction of land and material resources decreases, as reflected in light and dark purple (category 1) arrows. Materials discarded during extraction, manufacture, use, and at the end of product life decrease and the impacts of land and water contamination and pollution emissions are reduced. This is captured by light and dark gray arrows (category 2). The light and dark orange (category 3) arrows identify indirect impacts that result from recovery and recycling, such as reduced resource scarcity, raw material costs, and human health-related costs. Stocks affected are in blue. While the impacts of this SMM practice is indicated by changes in the “size” of arrows across diagrams, the effects on flows are not to scale; changes in stocks are likewise not pictured. (Adapted from: J. Fiksel, R. Bruins, A. Gatchett, A. Gilliland, and M. ten Brink. “The Triple Value Model: A Systems Approach to Sustainable Solutions.” *Clean Technologies and Environmental Policy: Volume 16, Issue 4 (2014)*, pp. 691-702.)

3.3.4 Energy Recovery in the Triple Value Framework

Energy recovery provides benefits that differ in some ways from recycling, but can overlap in others. Specifically, energy recovery through combustion of materials or methane capture reduces demand for other energy sources, particularly fossil fuel extraction and use, and reduces the associated ecosystem service degradation, energy use, GHG and pollutant emissions that are associated with fossil fuels. In addition, facilities that recover energy through combustion typically recover and recycle metals and other non-combustible materials to ensure efficient fuel blending.

One indication of the extent of potential material energy value is this fact: if the entire food scraps stream generated in the U.S. (34.75 million tons per year) were anaerobically digested, approximately 10 billion kWh of electricity (approximately 0.7 percent of U.S. residential electricity

demand in the U.S.) could be generated from the resulting biogas.⁶⁰ While this source does not have the generating potential of large-scale renewables such as solar, at a local level, the energy recovery potential, combined with the benefits of improved waste management, can be attractive. Specifically, energy recovery decreases solid waste disposal requirements, particularly for organic materials that are responsible for virtually all greenhouse gas emissions associated with MSW and are often sources of odor and land and water contamination. Energy recovery through combustion typically reduces waste volume by 90 percent, reducing demand for landfill space.⁶¹ Similar to recycling, indirect impacts of energy recovery include reduced threat of resource scarcity (e.g., fossil fuel use), avoided health and remediation costs, and increased jobs or local employment associated with energy production and distribution.

Figure 7 illustrates potential energy recovery impacts on material flows and on the economy, environment and society. A key positive impact in energy recovery is the production of energy from secondary materials. Similar to Figure 6 (recycling), energy recovery also reduces disposal of materials in landfills, and offsets some virgin material demand, particularly for fossil fuels. Figure 7 does not assume recovery of other materials (though as noted, combustion processes are often paired with recovery of metals and other non-combustible materials).

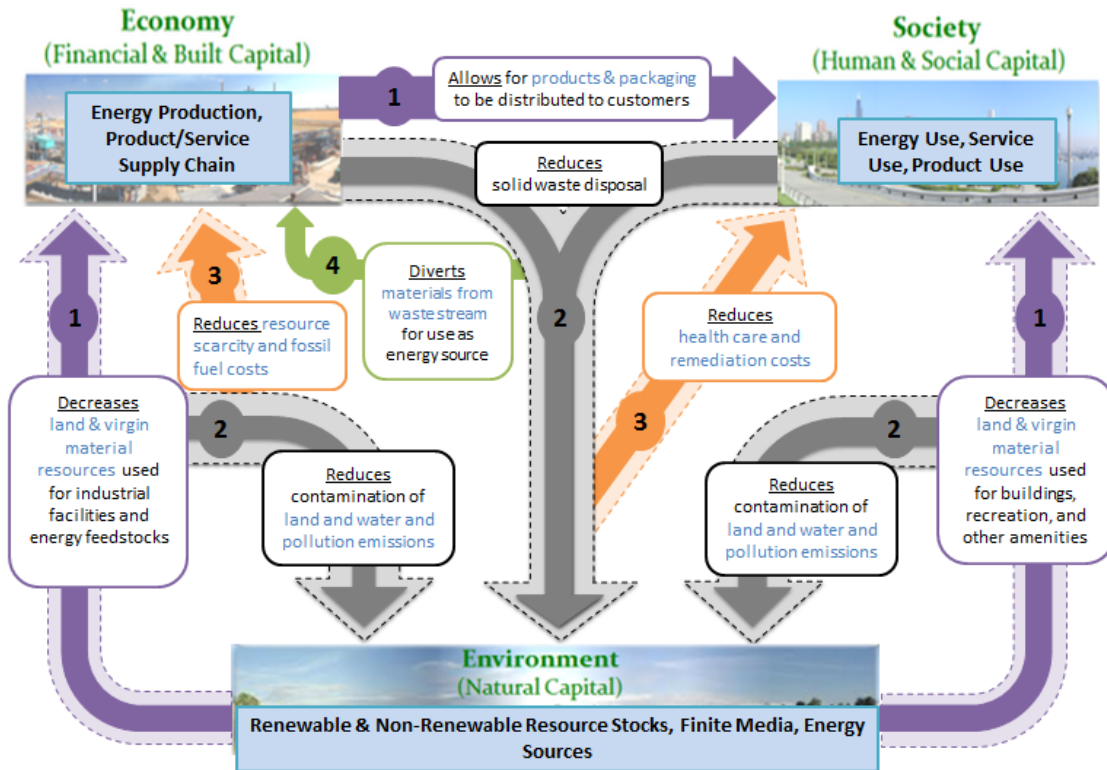
One strategic consideration for communities in adopting SMM strategies is the extent to which energy recovery options represent complementary or competing policies when considering recovery and recycling. While some materials are relevant only in one context (metals, which are not subject to energy recovery, and manures, which are difficult to “recycle” without digestion), organic materials such as plastic and paper have value both as fuel and as secondary materials. As communities investigate SMM options, the tradeoffs across these systems are important to consider.

⁶⁰ This fact assumes 3,200 standard ft³ methane generation potential per ton and 35% efficiency of internal combustion engines.

U.S. Environmental Protection Agency. Office of Research and Development. “Multimedia Environmental Assessment of Existing Materials Management Approaches for Communities.” September 2014.

⁶¹ U.S. Environmental Protection Agency. Office of Research and Development. “Multimedia Environmental Assessment of Existing Materials Management Approaches for Communities.” September 2014.

Figure 7. The economic, social, and environmental impacts of energy recovery in the triple value framework



Under energy recovery, materials are diverted from the waste stream to be used as an energy source; this is represented by the green (category 4) arrow. Product demand stays constant while extraction of land and material resources for energy feedstocks decreases, as reflected in light and dark purple (category 1) arrows. Materials discarded during extraction, manufacture, use, and at the end of product life decrease and the impacts of land and water contamination and pollution emissions are reduced. This is captured by light and dark gray arrows (category 2). The light and dark orange (category 3) arrows identify indirect impacts that result from energy recovery, such as reduced resource scarcity, fossil fuel costs, and human health-related costs. Stocks affected are in blue. While the impacts of this SMM practice is indicated by changes in the “size” of arrows across diagrams, the effects on flows are not to scale; changes in stocks are likewise not pictured. (Adapted from: J. Fiksel, R. Bruins, A. Gatchett, A. Gilliland, and M. ten Brink. “The Triple Value Model: A Systems Approach to Sustainable Solutions.” *Clean Technologies and Environmental Policy*: Volume 16, Issue 4 (2014), pp. 691-702.)

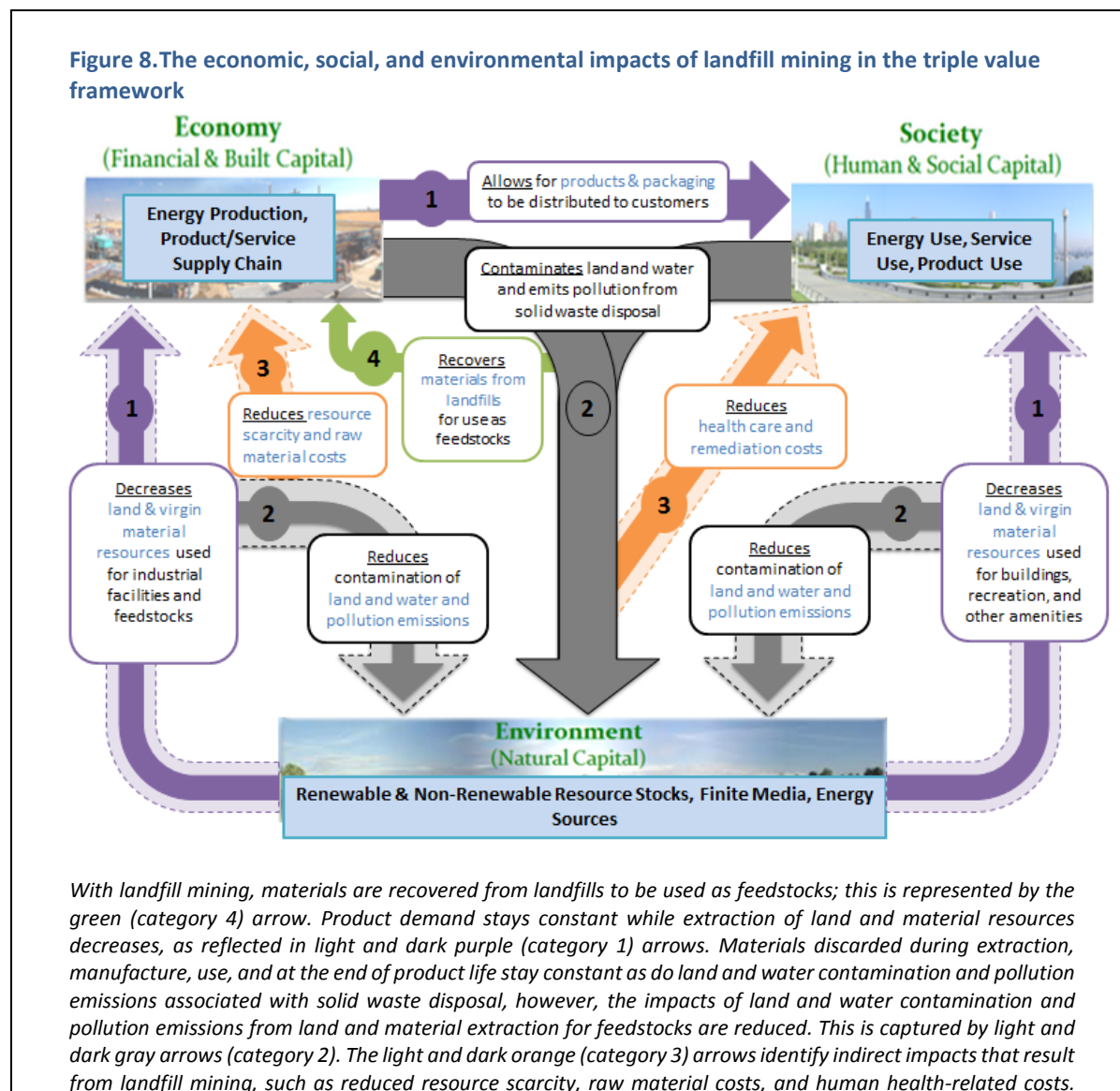
3.3.5 Landfill Mining

Landfill mining refers to a suite of existing and emerging technologies that aim to recover materials from MSW and C&D landfills. The strategy involves excavation and processing stabilized landfill material to recover materials with value, such as metals (ferrous metals can be recovered with magnets), stabilized organics, and other recyclables such as plastics. An estimated 32 landfill mining

projects have been executed in the U.S. but the technology has not reached broad economic viability.⁶²

3.3.6 Landfill Mining in the Triple Value Framework

Similar to recycling (and, if materials are recovered for energy value, energy recovery), landfill mining represents a method of materials recovery that could offset demand for virgin materials and resources. Figure 8 illustrates potential economic, societal, and environmental impacts of landfill mining on material flows. Although the impacts are similar to impacts of recycling, landfill mining occurs after disposal in landfills and does not affect initial solid waste disposal; land and water risks associated with landfills are not directly reduced. However, landfill mining could in some cases be part of remediation of landfill sites, and would in that context directly contribute to improvements in land use and ecosystem quality.



⁶² U.S. Environmental Protection Agency. Office of Research and Development. "Multimedia Environmental Assessment of Existing Materials Management Approaches for Communities." September 2014.

*Stocks affected are in blue. While the impacts of this SMM practice is indicated by changes in the “size” of arrows across diagrams, the effects on flows are not to scale; changes in stocks are likewise not pictured. (Adapted from: J. Fiksel, R. Bruins, A. Gatchett, A. Gilliland, and M. ten Brink. “The Triple Value Model: A Systems Approach to Sustainable Solutions.” *Clean Technologies and Environmental Policy: Volume 16, Issue 4* (2014), pp. 691-702.)*

As with recycling, indirect impacts of landfill mining include reduced threat of resource scarcity (e.g., fossil fuel and minerals), and increased local employment associated with mining. Figure 8 illustrates impacts that SMM policies involving landfill mining can have on material flows. Along with the benefits of recovering materials and avoiding virgin extraction and production, landfill mining may represent a new source of revenue and employment in communities during the implementation of landfill mining projects.

3.3.7 Product Take-Back

As part of an SMM strategy, product take-back can help ensure recovery and economical reuse of high-value materials by diverting them from the disposal system. Many take-back programs require coordination among policy-makers, point-of-sale merchants, and product manufacturers. Manufacturers, in particular, have a critical role in the success of these programs, both by accepting returned products, and, longer term, by developing products that minimize environmental impacts and facilitate return and remanufacture.

In the U.S., voluntary take-back programs have been implemented by some electronics companies for certain products such as computers and cell phones; in developing these programs companies have supported efforts to recover materials from these products for feedstock in new electronic products.⁶³ In 2012, electronic take-back networks handled 29.2 percent of the 3.4 million tons of electronic waste generated.⁶⁴ EPA reports that in 2010, 2,240 tons of cell phones were sent back to manufacturers, resulting in recovery of \$33.6 million in precious metals that year.⁶⁵ The recovery of such materials has reduced the demand for virgin materials, saving enough energy to provide electricity to 2,486 U.S. households per year.⁶⁶

3.3.8 Product Take-Back in the Triple Value Framework

Comprehensive product take-back programs implemented by the manufacturers and retailers have the direct effect of reducing the MSW material flows that communities must manage. The most important positive impact in product take-back is the direct recovery of materials by producers to be reused in the manufacture of new products. Materials recovered from these efforts offset demand for virgin materials and avoid impacts associated with material extraction and production. Indirect

⁶³ Electronics Take Back Coalition. “Facts and Figures on E-waste and Recycling.” June 25, 2014. Available at: <http://www.electronicstakeback.com/wp-content/uploads/Facts and Figures on EWaste and Recycling.pdf>

According to the Electronics Take Back Coalition, “experts estimate that recycling 1 million cell phones can recover about 24 kg (50 lb.) of gold, 250 kg (550 lb.) of silver, 9 kg (20 lb.) of palladium, and more than 9,000 kg (20,000 lb.) of copper.”

⁶⁴ Electronics Take Back Coalition. “Facts and Figures on E-waste and Recycling.” June 25, 2014. Available at: <http://www.electronicstakeback.com/wp-content/uploads/Facts and Figures on EWaste and Recycling.pdf>

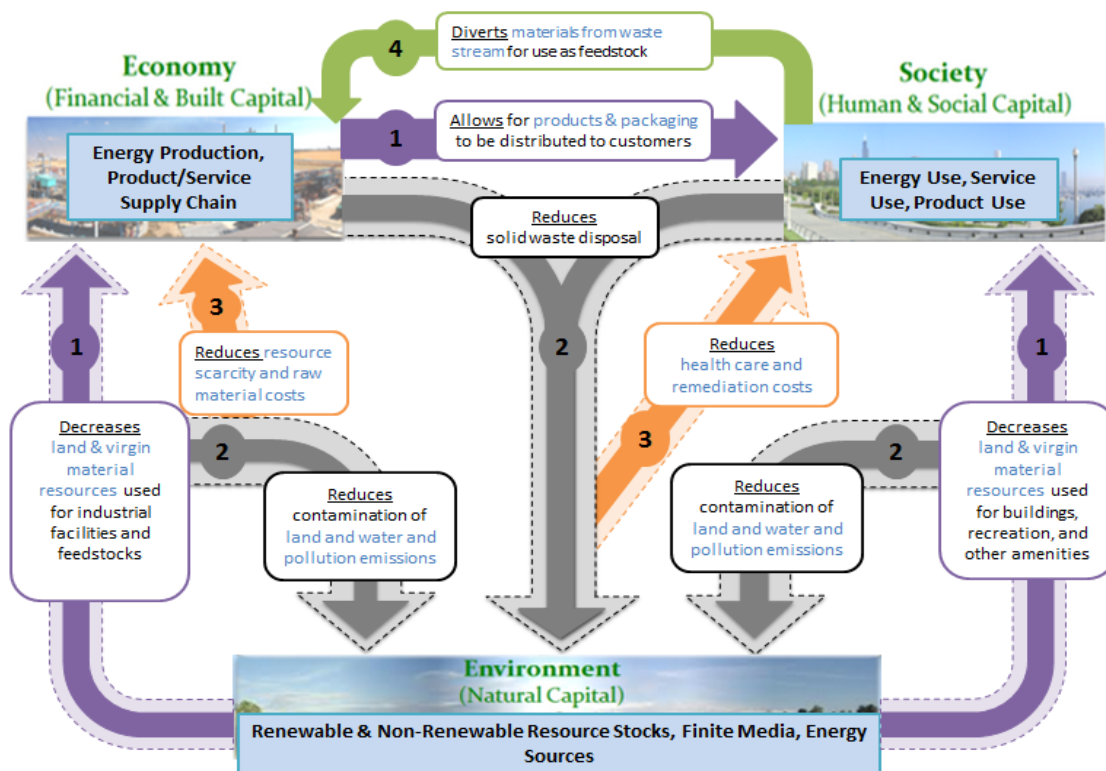
⁶⁵ Electronics Take Back Coalition. “Facts and Figures on E-waste and Recycling.” June 25, 2014. Available at: <http://www.electronicstakeback.com/wp-content/uploads/Facts and Figures on EWaste and Recycling.pdf>

⁶⁶ West, Larry. “Why Recycle Cell Phones?” *About News*. Available at: http://environment.about.com/od/mobilephones/a/why_recycle_cell_phones.htm

impacts of product take-back programs include reduced risk of resource scarcity and high raw material costs, reduced negative health effects, increased local employment association with collection, and reduced remediation costs. In addition, better product design and systems developed to use secondary materials can improve the efficiency of the manufacturers' business. Figure 9 illustrates the potential impacts of SMM strategies involving product take-back across the economy, environment, and society.

One consideration for communities in adopting SMM strategies is the extent to which product take-back represents complementary or competing policies when considering recovery and recycling. If local community recovery and recycling programs target materials slated for product take-back, recycling revenues from those materials could be affected. Moreover, multiple collection options could potentially confuse residents and affect recovery. As communities investigate SMM options, tradeoffs across these systems will be important to consider.

Figure 9. The economic, social, and environmental impacts of product take-back in the triple value framework



Under product take-back, materials are diverted from the waste stream to be used as feedstocks; this is represented by the green (category 4) arrow. Product demand stays constant while extraction of land and material resources decreases, as reflected in light and dark purple (category 1) arrows. Materials discarded during extraction, manufacture, use, and at the end of product life decrease and the impacts of land and water contamination and pollution emissions are reduced. This is captured by light and dark gray arrows (category 2). The light and dark orange (category 3) arrows identify indirect impacts that result from product take-back, such as reduced resource scarcity, raw material costs, and human health-related costs. Stocks affected are in blue. While the impacts of this SMM practice is indicated by changes in the "size" of arrows across diagrams, the effects on flows are not to scale; changes in stocks are likewise not pictured. (Adapted from: J. Fiksel, R. Bruins, A. Gatchett, A. Gilliland, and M. ten Brink. "The Triple Value Model: A Systems Approach to Sustainable Solutions." *Clean Technologies and Environmental Policy: Volume 16, Issue 4* (2014), pp. 691-702.)

3.3.9 Source Reduction

“Source reduction” encompasses a range of strategies to eliminate waste by reducing materials use upstream. Source reduction initiatives typically consider the entire product life-cycle footprint and target materials reduction throughout the system by changing product design, manufacturing processes, and/or supply and purchasing policies. Source reduction can enable manufacturers to rapidly increase productivity, reduce energy and materials costs, foster product and market innovation, and provide customers with value at less environmental impact.

Some source reduction strategies target certain materials (e.g., toxic substances and packaging); some consider energy use in manufacturing and long-distance transport in supply chains. Manufacturing changes generally aim to reduce water, energy, and materials use and waste generation. Beyond manufacturing, some source reduction occurs in residential settings as efficiency improvements, such as water-efficient fixtures.⁶⁷

Several high-profile corporate source reduction efforts have been documented in product manufacturing. For instance, Nestle Waters pledged to reduce plastic consumption across its brand portfolio. The company has redesigned its plastic water bottle so that it uses 60 percent less plastic than its original plastic water bottle design first introduced in the mid-1990s, reducing use of plastic resin for water bottle production by 80 million pounds annually.⁶⁸

3.3.10 Source Reduction in the Triple Value Framework

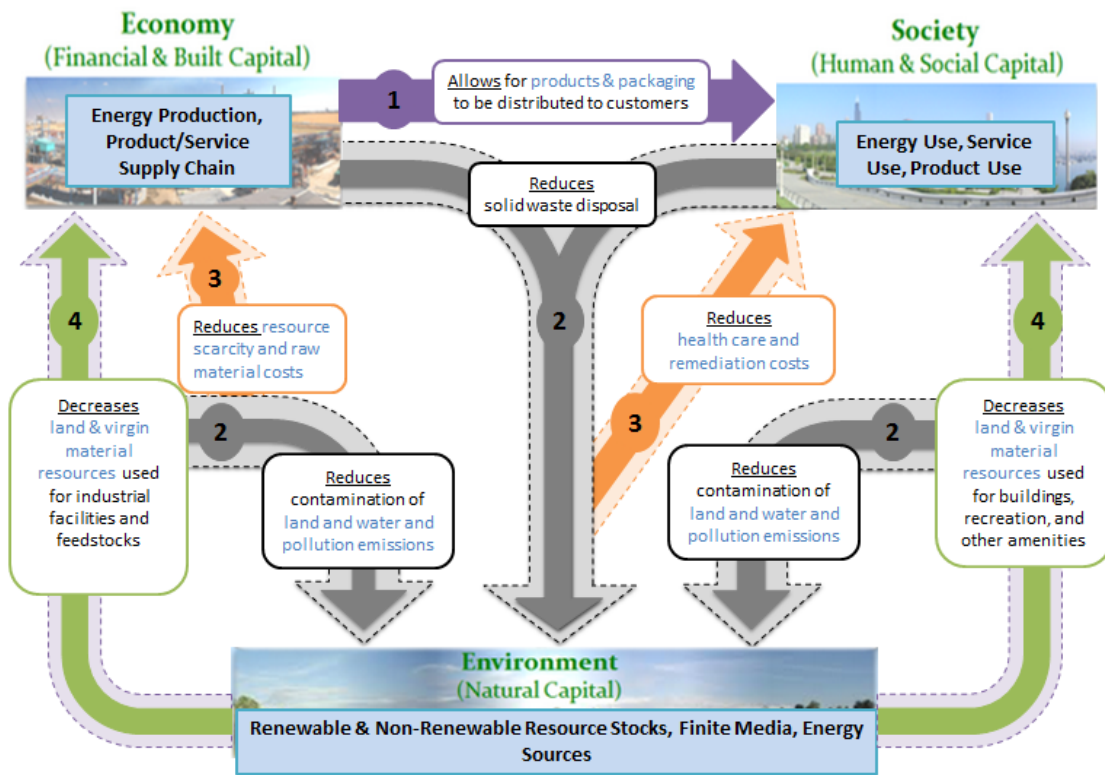
Depending on its design, source reduction can affect all parts of the system, reducing impacts across the life-cycle, and even reducing infrastructure demands such as buildings and transportation structures. Producing equivalent (or superior) goods with fewer material resources improves economic and social conditions while reducing environmental impacts (e.g., ecosystem degradation from resource extraction). As with other SMM approaches, these reductions in material demand can, in turn, reduce the risk of resource scarcity, high material costs, health impacts, and remediation costs.

Figure 10 illustrates the impacts of source reduction on material flows through the economy, environment, and society.

⁶⁷ U.S. Environmental Protection Agency. “Conserving Water.” April 24, 2014. Available at: <http://www.epa.gov/greenhomes/ConserveWater.htm#wateruse>

⁶⁸ Nestle Waters North America Inc. “Nestlé Waters North America Continues Plastic Reduction Efforts with New, Lighter Bottle.” December 15, 2009. Available here: <http://www.nestle-watersna.com/en/nestle-water-news/pressreleases/nestlewatersnorthamericacontinuesplasticreductioneffortswithnewlighterbottle>

Figure 10. The economic, social, and environmental impacts of source reduction in the triple value framework



Under source reduction, the feedstocks used as materials are decreased; this is represented by the green (category 4) arrow. Products and packaging are still distributed to customers while extraction of land and material resources for product production decreases, as reflected in light and dark purple (category 1) arrows. Materials discarded during extraction, manufacture, use, and at the end of product life decrease and the impacts of land and water contamination and pollution emissions are reduced. This is captured by light and dark gray arrows (category 2). The light and dark orange (category 3) arrows identify indirect impacts that result from source reduction, such as reduced resource scarcity, raw material costs, and human health-related costs. Stocks affected are in blue. While the impacts of this SMM practice is indicated by changes in the “size” of arrows across diagrams, the effects on flows are not to scale; changes in stocks are likewise not pictured. (Adapted from: J. Fiksel, R. Bruins, A. Gatchett, A. Gilliland, and M. ten Brink. “The Triple Value Model: A Systems Approach to Sustainable Solutions.” *Clean Technologies and Environmental Policy: Volume 16, Issue 4* (2014), pp. 691-702.)

3.3.11 Green Design

“Green design” is often paired with, or a component of, source reduction. The term green design refers to a collection of product and building philosophies, whose collective aim is to minimize environmental impact through mindful design.

Green design is most well-known in its application to the built environment, with programs such as LEED certification that focus on new building designs that reduce material use during construction and energy use during operations.

Product applications of green design include initiatives, such as “Design for the Environment”, that involve industry-led efforts to select safer chemicals and materials for products.⁶⁹ For instance, companies such as HP have utilized “Design for the Environment” principles to decrease the environmental impact of materials used in their products. In 2012, HP redesigned its products to use plastics free from hazardous substances, such as phthalates, brominated flame retardants, and polyvinyl chloride.⁷⁰ Currently, brominated flame retardants and polyvinyl chloride have been completely eliminated from their notebook products.⁷¹

3.3.12 Green Design in the Triple Value Framework

Green design, either as part of source reduction efforts or separately, emphasizes reduction in materials – especially hazardous materials – and energy use throughout product (and building) life-cycles. While broader source reduction efforts consider the entire life-cycle, design-for-environment policies place a specific emphasis on the “use phase” of products and structures. Particularly for long-lasting products and investments such as buildings and infrastructure, communities often have a significant interest in ensuring that their investments are efficient both in terms of cost and environmental impacts. Communities often contribute to green design initiatives through purchasing policies that favor products and construction meeting green design standards. Figure 11 illustrates the benefits of green design in the context of material flows and its interaction with the economy, environment, and society.

3.3.13 Green Remediation

Remediation of contaminated land is a critical challenge for communities, and sits at the intersection of land use and materials management. While SMM policies typically focus “upstream,” on materials associated with development and use of products, remediation has a significant materials component, both in the energy, tools, and materials needed for remediation itself, and in the challenge of extracting and disposing contaminants.

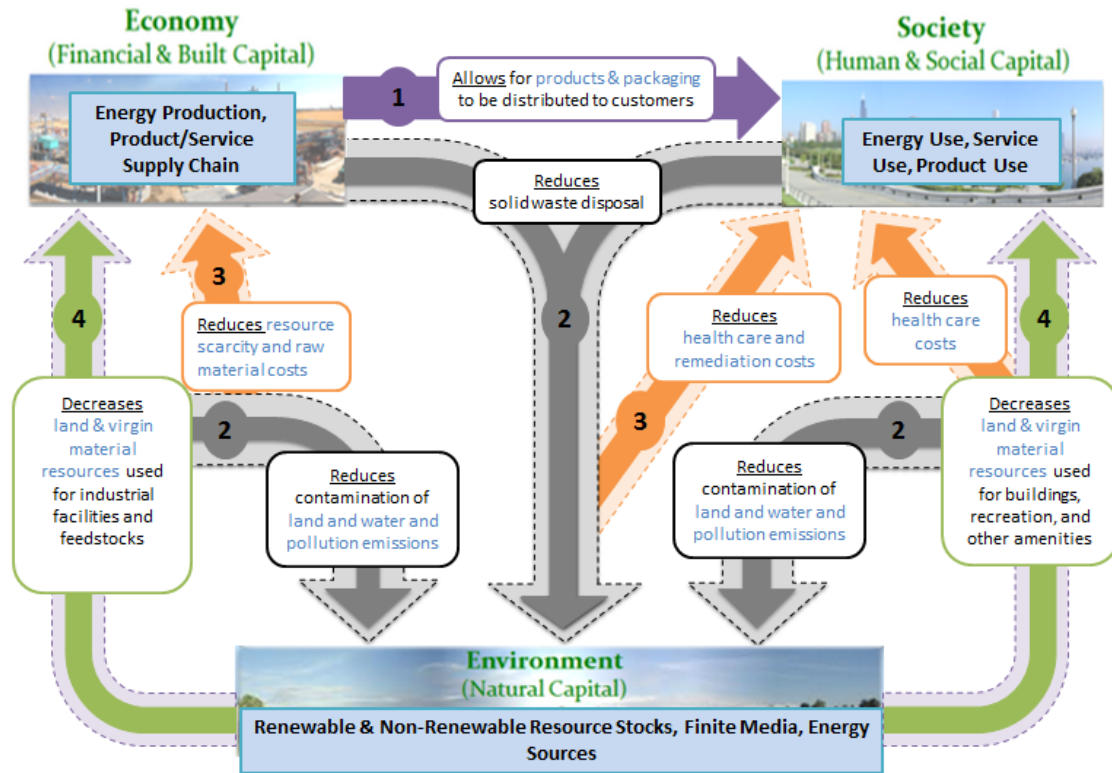
“Green remediation” refers to a suite of approaches that aim to reduce environmental impacts during cleanup actions. Green remediation approaches are often consistent with SMM principles. For instance, green remediation practices include recovering resources from demolition to be reused for later construction activities, recirculating water during clean up to reduce the use of fresh water, and using fuel-efficient devices or renewable forms of energy during clean-up to reduce demand of fossil fuel resources.

⁶⁹ U.S. Environmental Protection Agency. “EPA Design for the Environment.” June 24, 2014. Available here: <http://www.epa.gov/sustainability/analytics/epa-design.htm>

⁷⁰ HP. “Leading the Way Through a Leading Materials Strategy.” October 2013. Available here: <http://h20195.www2.hp.com/V2/GetDocument.aspx?docname=4AA4-8396ENW>

⁷¹ HP. “Leading the Way Through a Leading Materials Strategy.” October 2013. Available here: <http://h20195.www2.hp.com/V2/GetDocument.aspx?docname=4AA4-8396ENW>

Figure 11. The economic, social, and environmental impacts of green design in the triple value framework

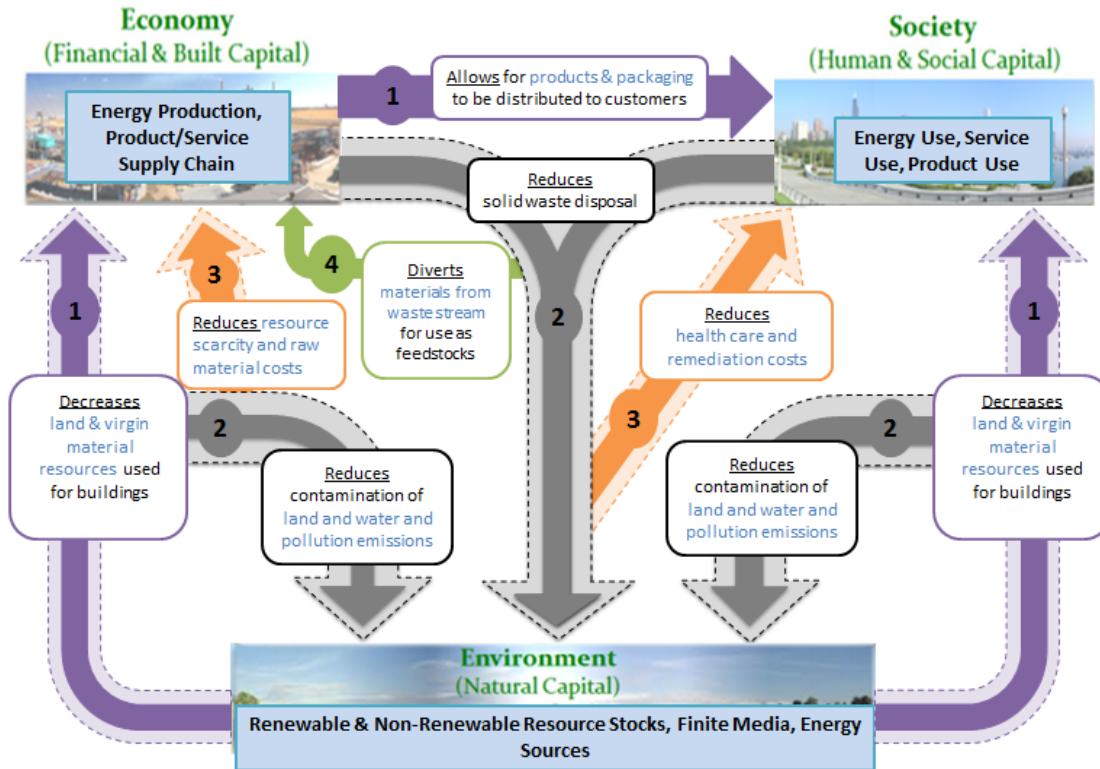


Under green design, the feedstocks used as materials, in particular, those made out of hazardous substances, are decreased; this is represented by the green (category 4) arrow. Product demand stays constant while extraction of land and material resources decreases, as reflected in light and dark purple (category 1) arrows. Materials discarded during extraction, manufacture, use, and at the end of product life decrease and the impacts of land and water contamination and pollution emissions are reduced. This is captured by light and dark gray arrows (category 2). The light and dark orange (category 3) arrows identify indirect impacts that result from green design, such as reduced resource scarcity, raw material costs, and human health-related costs. Stocks affected are in blue. While the impacts of this SMM practice is indicated by changes in the “size” of arrows across diagrams, the effects on flows are not to scale; changes in stocks are likewise not pictured. (Adapted from: J. Fiksel, R. Bruins, A. Gatchett, A. Gilliland, and M. ten Brink. “The Triple Value Model: A Systems Approach to Sustainable Solutions.” *Clean Technologies and Environmental Policy: Volume 16, Issue 4* (2014), pp. 691-702.)

3.3.14 Green Remediation in the Triple Value Framework

Green remediation intersects with other systems reflected in the triple value model by directly restoring degraded land to use, while simultaneously minimizing the use of other materials and energy. Like other SMM practices, indirect impacts of improved remediation include reduced impacts associated with the extraction and processing of materials and energy. Figure 12 illustrates the benefits of green remediation in the context of material flows and its interaction with the economy, environment, and society.

Figure 12. The economic, social, and environmental impacts of green remediation in the triple value framework



Under green remediation, materials are diverted from the waste stream to be used as feedstocks; this is represented by the green (category 4) arrow. Product demand stays constant while extraction of land and material resources decreases, as reflected in light and dark purple (category 1) arrows. Materials discarded during extraction, manufacture, use, and at the end of product life decrease and the impacts of land and water contamination and pollution emissions are reduced. This is captured by light and dark gray arrows (category 2). The light and dark orange (category 3) arrows identify indirect impacts that result from green remediation, such as reduced resource scarcity, raw material costs, and human health-related costs. Stocks affected are in blue. While the impacts of this SMM practice is indicated by changes in the “size” of arrows across diagrams, the effects on flows are not to scale; changes in stocks are likewise not pictured. (Adapted from: J. Fiksel, R. Bruins, A. Gatchett, A. Gilliland, and M. ten Brink. “The Triple Value Model: A Systems Approach to Sustainable Solutions.” *Clean Technologies and Environmental Policy: Volume 16, Issue 4* (2014), pp. 691-702.)

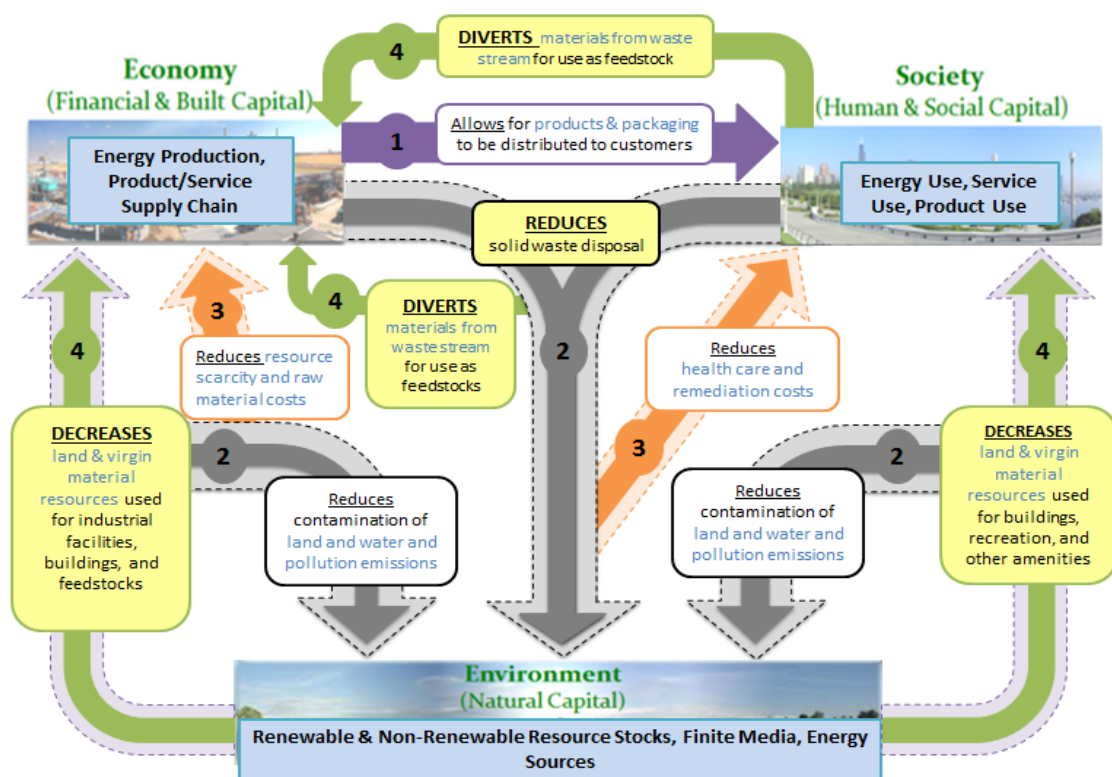
3.4 Summary of Impacts of SMM Practices

SMM practices, when carefully defined and adopted, can produce broad impacts across all the economic, social, and environmental stocks and systems in a community. SMM practices can affect economic stocks and structures by reducing demand for materials and resources (and therefore resource scarcity), and can increase jobs and local employment through extended post-consumer recovery and management of materials (a local “raw material extraction” from secondary sources).

Reduced demand for materials (and land) in one sector can also increase materials (and land) available for alternative uses.

Socially, SMM practices can reduce health care and remediation costs without compromising products and packaging for use. Environmentally, SMM practices can reduce the need for landfills, resource consumption, and ecosystem degradation; decrease overall contamination to land and water; and reduce GHG and other emissions. In addition to these general, high-level impacts, other environmental, economic, and social impacts may arise from the implementation of different SMM practices and impacts may vary depending on the community. Figure 13 illustrates the combined impacts of a comprehensive SMM approach to materials flow.

Figure 13. The combined environmental, economic, and social impacts of SMM approaches in the triple value framework



*In SMM, materials are diverted from the waste stream to be used as feedstocks and land and material resources used as feedstocks are reduced; this is represented by the green (category 4) arrows. Product demand stays constant while extraction of land and material resources decreases, as reflected in light and dark purple (category 1) arrows. Materials discarded during extraction, manufacture, use, and at the end of product life decrease and the impacts of land and water contamination and pollution emissions are reduced. This is captured by light and dark gray arrows (category 2). The light and dark orange (category 3) arrows identify indirect impacts that result from SMM, such as reduced resource scarcity, raw material costs, and human health-related costs. Stocks affected are in blue. While the impacts of this SMM practice is indicated by changes in the "size" of arrows across diagrams, the effects on flows are not to scale; changes in stocks are likewise not pictured. Material-related impacts from SMM practices are highlighted in yellow textboxes. (Adapted from: J. Fiksel, R. Bruins, A. Gatchett, A. Gilliland, and M. ten Brink. "The Triple Value Model: A Systems Approach to Sustainable Solutions." *Clean Technologies and Environmental Policy: Volume 16, Issue 4 (2014)*, pp. 691-702.)*

Table 4 provides an overview of impacts of these seven major SMM practices taken together. In reality, some of these practices in some cases are mutually exclusive, or do not combine to change the system in a way that best addresses the needs of the community implementing the SMM program.

While national governments and corporate actors tend to consider the broad impacts of SMM across the global supply chain, SMM practices can produce locally-specific impacts that reflect the conditions of the community. Table 4 provides a summary of the most common of these local economic, societal, and environmental impacts. It is these impacts that are most visible at the community level, and are most likely to inform the decision process about how to alter traditional materials and waste management practices.

Table 4. Summary of seven common SMM practices and example benefits in sustainability sectors

SMM Practice	Local Economic Impact	Local Societal Impact	Local Environmental Impact
Material Recovery and Recycling	<ul style="list-style-type: none"> - Direct: can create jobs from recycling collection and processing - Direct: can generate local revenue from sale of recovered materials 	<ul style="list-style-type: none"> - Direct: can increase traffic congestion from collection* - Direct: can improve health of residents near local landfill 	<ul style="list-style-type: none"> - Direct: can reduce contamination of land, water, and GHG and other emissions from landfilling - Indirect: can reduce degradation of land, water, and ecosystem services from decreasing demand for virgin materials
Energy Recovery	<ul style="list-style-type: none"> - Direct: can create jobs at energy recovery plant - Direct: can directly reduce energy costs for community by providing a local source of energy* 	<ul style="list-style-type: none"> - Direct: can increase traffic congestion from collection* - Direct: can improve health of residents near local landfill 	<ul style="list-style-type: none"> - Direct: can reduce contamination of land, water, and GHG and other emissions from landfilling - Indirect: can reduce land use demand for transmission lines, other energy sources*
Landfill Mining	<ul style="list-style-type: none"> - Direct: can create landfill mining jobs - Direct: can generate local revenue from sale of recovered materials 	<ul style="list-style-type: none"> - Direct: can reduce human health issues from exposure to toxics or pollution from landfill 	<ul style="list-style-type: none"> - Direct: can reduce contamination of land, water, and GHG and other emissions from landfilling - Indirect: can reduce degradation of land, water, and ecosystem services from decreasing demand for virgin materials
Product Take-Back	<ul style="list-style-type: none"> - Direct: can generate local revenue if companies pay for materials returned (e.g., bottle deposits) 	<ul style="list-style-type: none"> - Indirect: can improve health of residents near local landfill by reducing materials sent to landfill - Indirect: can improve street aesthetics by decreasing littering 	<ul style="list-style-type: none"> - Direct: can reduce contamination of land, water, and GHG and other emissions from landfilling - Indirect: can reduce degradation of land, water, and ecosystem services from decreasing demand for virgin materials

SMM Practice	Local Economic Impact	Local Societal Impact	Local Environmental Impact
Source Reduction	<ul style="list-style-type: none"> - Direct: can reduce volume of discarded materials and costs - Indirect: can contribute to lower cost products from decreased materials intensity 	<ul style="list-style-type: none"> - Direct: can reduce traffic if materials volume is lower - Indirect: can improve health of residents near local landfill by reducing materials sent to landfill 	<ul style="list-style-type: none"> - Direct: can reduce contamination of land, water, and GHG and other emissions from landfilling - Indirect: can reduce degradation of land, water, and ecosystem services from decreasing demand for virgin materials
Green Design	<ul style="list-style-type: none"> - Direct: can produce cost savings to user (e.g. if products are designed to use less energy)* 	<ul style="list-style-type: none"> - Indirect: can improve health of residents near local landfill by reducing materials sent to landfill - Direct: can improve health of residents and manufacturers through the product use phase (e.g., if products are designed with less hazardous materials) 	<ul style="list-style-type: none"> - Direct: can reduce contamination of land, water, and GHG and other emissions from landfilling - Indirect: can reduce degradation of land, water, and ecosystem services from decreasing demand for virgin materials
Green Remediation	<ul style="list-style-type: none"> - Direct: can increase land value* 	<ul style="list-style-type: none"> - Direct: can improve health of residents near local contaminated lands 	<ul style="list-style-type: none"> - Direct: can reduce contamination of local land and water
*denotes intersections with either infrastructure, transportation, and/or land use			

Critical to identifying successful SMM strategies is identifying and understanding the endpoints that most affect the communities that lead implementation while also ensuring that broader material flows, including national and global impacts, are considered. Because most SMM efforts integrate a number of different practices addressing different parts of the material flow system, a key step in designing an approach is to identify the most significant interactions among practices, with a focus on:

- Practices that share endpoints
- Practices that are mutually exclusive
- Practices that must be done sequentially
- Practices that are/are not “local” in their impacts

Practices are also differentiated by the stakeholders (including different levels of government and public/private sector stakeholders) who have the authority to select, implement, and, in some cases, finance SMM practices, and also by the costs that accrue to communities and the relative timing of costs and benefits.

Because the purpose of SMM is to bring about system-level changes that benefit the environmental, social, and economic systems in a community, the issues that draw these different systems together represent areas for careful focus. While the specific contours of a community and its material practices will affect the selection of specific SMM strategies, a number of areas of intersection across and among economic, environmental, and social systems are likely to demand specific stakeholder and analytic attention:

- **The economic structure of the existing materials management system.** The contracts, practices, infrastructure, and economic relationships that connect the private organizations, public entities, and residents of a community can be a source of funding and momentum for SMM, and also a source of opposition or barriers. To be successful, SMM efforts must account for current systems, and the costs to the various participants associated with making structural changes in materials management, and the links between the social and economic capital represented by solid waste and other materials management.
- **The extent and nature of local environmental impacts.** While SMM strategies can affect local communities, materials and products are also globally traded, with impacts that often occur across the world. To evaluate SMM options, it is important to clarify the local environmental impacts associated with a strategy, because these are most directly comparable to local costs in considering economic and social impacts of a policy.
- **The role of broader impacts in SMM.** Separately, communities should consider the more remote benefits associated with SMM; these can be significant and compelling reasons to pursue SMM even when local impacts are modest.
- **The link between materials and social capital.** In examining SMM options, the social impacts of current materials use may represent a critical intersection. Materials, products, and processes can be designed to improve human health and social (e.g., frequent trash removal to improve quality-of-life); implementation of SMM must ensure that the services of importance in communities are maintained or upgraded with new processes.

In all of these matters, communities and others with interest in SMM need analytic support. EPA and SHCRP can assist stakeholders in recognizing and assessing the significant intersections across these practices, and across the actors who implement them, in order to ensure successful SMM program design. Section 4 of this paper explores these relationships in more detail, and notes several potential areas in which EPA may provide important insights.

Section 4: Strategies for Support of Sustainable Materials Management

SCHRP and EPA's focus is to assist communities and other stakeholders to design SMM strategies that improve economic, environmental, and social conditions at the community level. In theory, SMM represents a beneficial change to material flows in all contexts, and reduces the total cost of materials management for communities either directly, by reducing material volume and associated management costs, or in other important ways, such as reduced energy use, emissions to air, water, and land, and the impacts on health and the economy that are associated with these emissions and with inefficient materials use.

In practice, as noted in Section 2.3, SMM implementation is slowed by a number of structural barriers associated with the cost of some projects, and their difference in structure and timing from established practices and materials management contracts, combined with limited authority and coordination among key stakeholders, and in some cases limited or delayed direct and measurable cost savings to communities. To address these barriers, stakeholders need reliable, readily available information and tools that can help them effectively assess SMM options and communicate the results of their investigations to each other. By definition, SMM involves complex interactions that cross many areas of environmental policy. Re-aligning policies and practices with SMM principles can be a powerful way to improve the sustainability of communities, but analysis to assess the trade-offs and benefits associated with SMM options is needed.

Analysis of SMM options takes place within the systems that it seeks to change; the effective evaluation of SMM options requires:

- **Environmental information** about the natural resources and environmental effects of current materials management processes, including local effects visible in the community considering SMM and broader effects such as global materials extraction.
- **Economic information** about the structure of financial arrangements for managing materials, the costs and economic benefits of SMM options, and the timing and magnitude of potential changes to the economy related to materials.
- **Social and human impact information** about the community or communities considering SMM, including materials-related impacts on quality of life, priorities for improvements at the community level, and the structure of authority for implementing change (including SMM policies) at key levels of government.

SCHRP's role in furthering adoption of SMM includes making available tools for analysis and, of equal importance, assisting in the design and use of a process that systemically involves stakeholders to clarify priorities, select options, and address economic and other implementation barriers. This section outlines an approach to evaluating SMM strategies that highlights options and priorities for model development, analysis, and implementation that may guide SCHRP in its efforts to support SMM.

4.1 Approach to Designing and Implementing SMM

The design and evaluation process for SMM strategies follows four basic steps that capture a system-level approach reflective of the triple value model. These steps are generally consistent with many other policymaking efforts, except that they emphasize the human (stakeholder) systems that

drive and restrict adoption of SMM strategies. In addition, the process as a whole is designed to be iterative:

- **Step 1:** Identify key stakeholders and stakeholder goals for the community related to materials and to other systems with which they overlap (e.g., transportation).
- **Step 2:** Develop data and options for achieving SMM and other sustainability goals, with a focus on endpoints in all parts of the triple value framework (economic, social, and environmental impacts) associated with options. Ensure that materials strategies under consideration are consistent with SMM principles and reflect the priorities of stakeholders.
- **Step 3:** Assess the practical feasibility of SMM options in the specific context defined by the stakeholder process. Use data collected about the community structures and systems to screen SMM options and address obstacles to implementing those options determined to be practical.
- **Step 4:** Prioritize and conduct analyses to assess the key costs, benefits, and interactions among feasible SMM options. This includes identifying community-level and higher-level costs, benefits, and obstacles for each option, and considering the timing and geographic scope of impacts.

This process is iterative, and can take place at many scales, from local to regional to national, even global, involving multiple governments and global corporations. Important at each stage, however, is an understanding of the tools and options that can support the process. The following sections will further explore each of the four steps required to design and evaluate SMM strategies.

4.2 Step 1: Identify Key Stakeholders and Stakeholder Goals

A critical and often unpredictable element of SMM efforts is identifying key stakeholders who represent different parts of the materials system and can, together, ensure implementation of an SMM strategy. While this paper focuses on a community level, SMM challenges communities to think beyond traditional structures, boundaries and policies, and to identify and involve stakeholders throughout the materials system who would be affected by an SMM effort. This can involve adjacent communities, regional or state authorities, federal entities, and corporations of all sizes. Engagement of stakeholders throughout the decision process ensures that parties supporting and providing critical perspectives understand the trade-offs and benefits of SMM, and that all factors of importance to the community are considered in deliberations.

In bringing together the primary stakeholders to support SMM, a community should emphasize the following:

- Specific environmental priorities and goals (e.g., increasing open space, reducing emissions)
- Significant economic and social challenges and priorities (e.g., reducing the cost of disposal)
- Economic or social priorities that cannot be compromised, and may be difficult to reconcile with SMM principles (e.g. ensuring consistent supply of products and goods to communities)

SMM goals should both guide and emerge from the stakeholder process, reflect the unique conditions of the community and stakeholders involved, and to the extent practicable, focus on measurable results and outcomes. In many cases, materials issues are interconnected with land use, transportation, and other decisions, and may involve broader regional input. In considering

materials-related challenges, however, communities often converge around one or more of the common SMM objectives noted in Section 2:⁷²

- Decrease urban demand for material consumption
- Decrease resource intensity of products & services
- Use substitute materials with lower life-cycle impact
- Encourage local sourcing of materials & products
- Increase recycling rates for commodity materials
- Recover and reuse wasted or underutilized resources
- Assure proper disposal for unwanted solid wastes

These objectives focus on activities, and often impacts, of community-level materials management decisions, and can be combined with each other or with other objectives to expand the reach of an SMM effort. A critical feature, however, is the focus of SMM on integrated economic, environmental, and social impacts, and its adherence to the participatory philosophy outlined in the OECD principles.⁷³

The Role of Identifying Key Stakeholders and Stakeholder Goals in SMM

Identifying key stakeholders and stakeholder goals early on in the SMM process can help to define environmental, social, and economic goals of communities and identify a feasible portfolio of SMM practices to help achieve those goals. Metro Vancouver used a targeted stakeholder approach to support efforts to find a wastewater treatment plant solution that integrated economic, environmental, and social values in implementing resource recovery from both liquid and solid waste streams. Metro Vancouver held community events and public meetings to:⁷⁴

- engage potentially impacted stakeholders in the design and funding of the new treatment plant;
- encourage stakeholders to share identified issues of liquid and solid waste; and
- promote awareness of the need for a solution to manage liquid and solid waste sustainably.

Using results from the stakeholder process, Metro Vancouver was able to build and design a wastewater treatment plant with nutrient recovery and effluent reuse that was designed to:⁷⁵

- protect and enhance natural ecosystems;
- increase biofuel use;
- reduce water consumption; and
- divert 70% of solid waste from landfills by 2015.

⁷² These objectives are derived from the principles and framework presented in Fiksel, J. 2006a. A framework for sustainable materials management. *Journal of the Minerals Metals & Materials Society* 58 (8):15–22.
http://www.eco-nomics.com/images/Framework_for_SMM.pdf

⁷³ Principles for SMM recommended by OECD presented in: OECD. “Green Growth Policy Brief: Sustainable Materials Management.” October 2012. Available at:
http://www.oecd.org/env/waste/SMM%20synthesis%20-%20policy%20brief_final%20GG.pdf

⁷⁴ Metro Vancouver. “Services and Solutions for a Livable Region.” Available at:
http://www.cwwa.ca/pdf_files/2014Award_MetroVancouver.pdf

⁷⁵ Fidelis Resource Group. “Integrated Resource Recovery Study - Metro Vancouver and the North Shore Communities (Executive Summary).” March 29, 2011.

At this stage of the design, data describing systems and issues may be important, but analytic tools are less central. A more central need that many communities have at this stage is the expertise to manage a complex stakeholder process that can involve multiple governments, citizens' organizations, and private sector entities. EPA's experience in designing and guiding similar processes could provide needed leverage and ensure that the process is efficient and well-focused.

4.3 Step 2: Array SMM Practices to Develop Options for Achieving Goals in the Context of the Stakeholder Process

When the key stakeholders in a community context have converged on the goals and objectives around which an SMM strategy should be designed, the next step is to research and identify the specific activities and practices that might comprise an effective SMM strategy. Some activities align or combine more readily to support different SMM goals. Table 5 below illustrates a matrix that shows the intersection between the SMM goals and the common practices that have been outlined in this paper.

The challenge for each community is to construct the right portfolio of SMM practices for a community. The triple value framework provides a strong conceptual starting point for developing a set of SMM options. The conceptual maps can help identify options that affect specific, targeted material flows and support specific SMM goals, and array the specific impacts that result from specific SMM practices.

Information that supports this stage of the SMM process includes:

- Up-to-date descriptions of potential SMM approaches and technologies;
- Documented examples of the impacts of specific SMM strategies and technologies;
- Resources for investigating the economic and governance structure of existing materials management services, (e.g., to understand systems and help identify key decision-makers); and
- Summary-level information characterizing critical system components and intersections.

At this stage, it is important to identify and characterize the system intersections that might drive or prevent the success of a strategy. The specific relationships will vary among communities, but represent areas where the different elements in the triple value framework are most interconnected. Common areas of system intersection occur between economic and social structures, and tend to include established social and physical structures that create barriers to change. One example might be a local landfill, run at a low cost by local firms; the facility provides jobs while reducing tax burdens on residents, but its long-term impacts might include land use constraints, environmental degradation and social human-health issues. These critical points of interaction that govern the movement and management of materials may extend beyond materials policy and beyond the political boundaries of a single community, but they will form the core of the analyses of different options for achieving system-wide improvements.

Table 5. Matrix detailing the intersections between SMM practices and goals

SMM Goals	Recycling	Energy Recovery	Landfill Mining	Product Take-Back	Source Reduction	Green Design	Green Remediation
Decrease urban demand for material consumption	✗	✗	✗	✗	✓	✓	✗
Decrease resource intensity of products and services	✓	✓	✓	✓	✓	✓	✓
Use substitute materials with lower life-cycle impact	✓	✓	✓	✓	✓	✓	✓
Encourage local sourcing of materials and products ⁷⁶	✓	✓	✓	✓	✗	✓	✓
Increase recycling rates for commodity materials	✓	✗	✓	✓	✗	✓	✓
Recover and reuse wasted or underutilized resources	✓	✓	✓	✓	✗	✓	✓
Assure proper disposal for unwanted solid wastes	✓	✓	✗	✓	✗	✗	✓
Create economic incentives for material efficiency	✗	✗	✗	✗	✓	✓	✓
SMM practices can be employed in tandem to create a portfolio of strategies to optimize the positive impacts of SMM. The exhibit indicates which practices do and do not support specific SMM goals, and provides some indication of practices that are complementary (in that they support separate goals) and practices that might compete or be redundant.							

4.4 Step 3: Assess the Practical Feasibility of SMM Options Developed in the Stakeholder Process

When a community or group of stakeholders has reviewed potential SMM options that are consistent with agreed SMM goals, another factor in selecting the best set of options is the regulatory and economic feasibility of different practices in the specific context.

Regulatory (policy) feasibility considers the constraints imposed by local, state, and federal laws, and by existing contracts for management of materials and related infrastructure. Communities can implement the SMM practices discussed above through a number of local policies, but these actions often require cooperation with and approval from other stakeholders, or compliance with the terms of existing contracts and state and federal regulations. Particularly when SMM policies affect site remediation or management of landfills, federal and state statutes governing site use and financing

⁷⁶ All SMM practices, with the exception of source reduction, can encourage local sourcing of materials and products if facilities for recycling/recovery/landfill mining/manufacture/remediation are located near the community in question.

can constrain options for SMM activities. Other SMM practices typically require coordination with regional and state authorities, particularly in places where regional markets for waste already exist. Table 6 identifies common community program and policy options associated with SMM strategies, and notes the other authorities that may be required for implementation.

Table 6. Community-level programs and policy options and other important authorities to involve to implement SMM Practices.

SMM Practice	Community Program/Policy Options	Other Important Authorities
Recycling/ Materials Recovery	<ul style="list-style-type: none"> • Curbside recycling programs • Pay-As-You-Throw programs • Single stream vs. dual stream 	<ul style="list-style-type: none"> • Private waste haulers; municipal and regional contracts • Regional waste disposal facilities • State recycling requirements
Energy Recovery	<ul style="list-style-type: none"> • New facilities; capital projects <ul style="list-style-type: none"> ◦ Anaerobic digesters ◦ MSW energy recovery facilities • Landfill gas recovery systems 	<ul style="list-style-type: none"> • Regional waste management and generation • Utilities and distribution companies • State and Federal regulations for energy recovery facilities • Private landfill operators
Landfill Mining	<ul style="list-style-type: none"> • Incentive policies (e.g., secured secondary market for recovered materials) • Permits to private sector recovery interests 	<ul style="list-style-type: none"> • State and Federal regulations regarding management of closed or active landfills • Private landfill miners, operators
Product Take-Back	<ul style="list-style-type: none"> • Local ordinances/landfill bans • Permitting requirements for local businesses 	<ul style="list-style-type: none"> • State regulations • Federal, industry voluntary programs
Source Reduction	<ul style="list-style-type: none"> • Government procurement and purchasing requirements • Packaging requirements and guidelines • Labeling guidelines • Material/packaging bans (e.g., plastic bags) 	<ul style="list-style-type: none"> • State and Industry-specified requirements for content, labeling
Green Design	<ul style="list-style-type: none"> • Building standards such as LEED • Design requirements, e.g., low-impact materials, energy efficiency, recyclability 	<ul style="list-style-type: none"> • State, Federal standards for building, infrastructure, product specifications • Industry product specifications (e.g., ASTM, etc.)
Green Remediation	<ul style="list-style-type: none"> • Land reuse ordinances • Remediation requirements for hauling waste 	<ul style="list-style-type: none"> • State, Federal remediation standards, use restrictions, financing restrictions

Often the involvement of other levels of government and private sector stakeholders can be a catalyst and resource for a successful SMM program rather than a barrier. For all SMM-related policy options, however, communities should identify existing regulatory requirements and regional authorities governing materials management, and regional patterns and markets for materials. For each option, an assessment of the regulatory and market context can help prioritize SMM practices.

Economic and market feasibility assessments consider, at a screening level, the costs, cost savings, and market impacts associated with SMM practices, given the size and nature of material flows, the regional and local structure of the existing materials recovery and management industry, and community-specific characteristics such as population density and the existing facilities, contracts, ordinances, and financing operations governing materials management. In some cases, well-established thresholds for waste quantities exist below levels in which a facility is not economically viable (e.g., energy recovery technologies).

A useful resource for communities considering the feasibility of SMM alternatives would be a centralized tool/data repository that could provide information about regional and state regulations, statutes, and markets governing different standard SMM-related practices. A screening tool could identify potential partners, markets, and barriers to different practices, and assist communities in developing viable options without conducting extensive research. Currently, there are efforts to develop such a tool throughout the various projects at SHCRP. SCHRP could continue to connect and integrate relevant SCHRP projects and project activities to secure such a screening tool.

In tandem with tools for understanding the policy landscape, resources that enable a community to rapidly assess its use of materials and energy, and conduct screening-level assessments of feasibility for particular SMM technologies or practices, would be useful.

One option could be a reduced-form tool based on “urban metabolism” principles. Urban metabolism is an approach that maps and quantifies energy, water, food, and other material inputs as well as waste outputs for a community.⁷⁷ By mapping energy and material quantities and flows, analysts can assess a community’s energy efficiency, materials recycling, and waste management system to better inform which SMM practices are feasible for implementation.

⁷⁷ Zhang, Y. “Urban Metabolism: A Review of Research Methodologies.” *Environmental Pollution*. 2013. 178: 463-473

Urban Metabolism

Urban metabolism is a framework used to describe and analyze the flows of materials and energy and study the interactions of natural and human systems within cities. In the context of SMM, urban metabolism provides an effective way to gain information on energy efficiency, materials recycling, waste management, and the infrastructure of an urban system.⁷⁸ The diagram below outlines the steps typically taken to understand the flows of energy and materials within the urban metabolism framework.

Figure 14. The urban metabolism framework

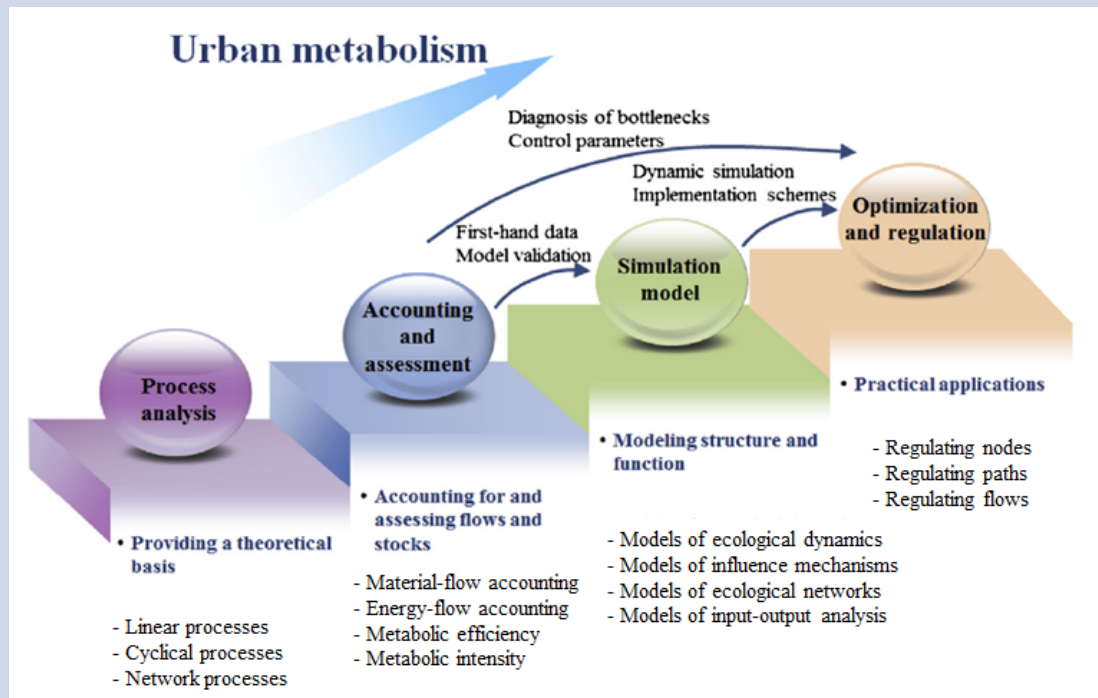


Figure from: Zhang, Y. "Urban Metabolism: A Review of Research Methodologies." *Environmental Pollution*. 2013. 178: 463-473

The following table summarizes different accounting methods to determine the inputs and outputs of a community's material and energy flows.

⁷⁸ Zhang, Y. "Urban Metabolism: A Review of Research Methodologies." *Environmental Pollution*. 2013. 178: 463-473

Table 7. Methods to map and quantify community flows of materials and energy⁷⁹

Method	Description
Material flow analysis (MFA)	MFA is a method for quantifying flows and stocks of materials or substances in a well-defined system, such as a community. Quantifying flows and stocks of materials allows analysts such as communities to determine the material composition and quantity of wastes. These data help frame and prioritize different policies for materials management.
Energy flow analysis	Energy flow analysis is a method for quantifying flows and consumption of energy in a well-defined system, such as a community. Quantifying flows and consumption of energy allows analysts to determine where and when energy is lost to better frame and prioritize policies to improve energy efficiency.
Ecological footprint analysis	Ecological footprint analysis is an accounting tool that measures the amount of natural resources, (e.g., land, water, etc...) to support production and consumption of products. Quantifying how natural resources are used for material production helps frame and prioritize different policies for sustainable materials management.

Essential to this stage of the SMM implementation process is the availability of feasibility assessment options that do not require broad and expensive analyses. Models and tools that are calibrated to compare SMM options with statutory, contractual, environmental, or economic thresholds and limits (using limited, high-level information characterizing materials and energy use) can help communities identify situations where:

- SMM options would require changes in policy or contracts for implementation;
- Technological or economic barriers exist at the current project scale;
- Options involve other systems (e.g., infrastructure); and/or
- Approaches under consideration may not have the desired scale of impacts.

In all of these cases, communities could respond by either scaling a project differently (e.g., involving a broader set of communities or considering policy changes) or selecting a different SMM strategy. The outcome of this step, which may involve engaging new stakeholders and considering new options (reiterating Steps 1 and 2), would be a “short list” of the SMM options that are deemed feasible.

4.5 Step 4: Prioritize and Conduct Analyses to Assess Key Costs, Benefits, and Interactions among Feasible SMM Options

SHCRP’s central role in furthering SMM efforts is to provide communities with tools that enable robust, streamlined assessments of SMM options. Specifically, to identify an SMM strategy that 1) is consistent with SMM principles, 2) is economically and politically feasible, and 3) is preferable to both the “business as usual” scenario and any other robust alternatives under consideration, it is critical to identify and estimate the most important system-level benefits and costs of each proposed SMM practice for each goal.

Ideally, it would be feasible to perform a system-level evaluation that considered all direct and indirect costs, benefits, and interactions associated with SMM practices. However, the unique features of every SMM project and community and the complexity of the global system of material

⁷⁹ Zhang, Y. “Urban Metabolism: A Review of Research Methodologies.” *Environmental Pollution*. 2013. 178: 463-473

flows prevents the development of a cost-effective, transferrable, and comprehensive model with which to conduct specific assessments. Instead, EPA and SHCRP may wish to prioritize the development of tools, which assess:

- **Cost (and cost savings):** SMM practices represent an opportunity for cost savings for both communities and businesses. The economic benefits can be an important motivation for adoption of such practices. Resource-constrained communities will not typically adopt any materials strategy that is more costly than the current system, and offers no other benefits that might justify added costs. However, communities often limit cost analyses to engineering and financing costs for capital projects, and do not identify or calculate cost savings or revenue opportunities that might accrue to the local community based on SMM practices (e.g., tax revenues from properties near a remediated site). Therefore, costs form a central basis of comparison across options, and a cost assessment that captures changes across the triple value framework can, even if not comprehensive, illustrate far-reaching impacts of SMM.
- **Social impacts:** Due to the effectiveness of regulations in the U.S., local environmental impacts associated with end-of-life management of materials are often limited; safely maintained landfills and manufacturing facilities do not typically have emissions that cause immediate health effects. However, social impacts associated with materials management, including traffic and undesirable land uses (e.g., landfills and other facilities), are visible and often important in developing policy options. Solutions that capture, even qualitatively, direct and indirect impacts of SMM projects such as reduced traffic, improved open space opportunities, or, in one example, a sludge digester that reduces odors in a neighborhood, are likely to enjoy significant support based on these local and sometimes high-value impacts.
- **Economic impacts:** Separate from cost, it is important to consider economic impacts on the implementing community/communities, including temporary and permanent impacts on employment, changes in tax revenues, and other highly visible effects of changes in materials management. In particular, it is important to identify employment involved in recovering secondary commodity materials or energy from waste not as “waste management” but as “materials extraction/production” – for this work parallels virgin production and provides the same raw materials to established markets.
- **Links between SMM and Building/Infrastructure/Transportation/Land Use:** Similar to social benefits, SMM approaches that have “reach” into highly visible (and costly) community needs such as public buildings and infrastructure (e.g., a C&D recycling effort, or green design requirements that affect building stock) are likely to receive more support from key stakeholders; these intersections often highlight the long-term nature of SMM benefits as well, which are often overlooked in the traditional idea of materials management as “trash pickup.”
- **Environmental impacts associated with avoided extraction and production:** Like costs, avoided environmental impacts do not typically accrue directly to the community implementing the SMM policy. However, the scale of these impacts can be significant, and can demonstrate the far-reaching impact of even a limited local policy. In addition, the ready availability of life-cycle inventories for a wide array of materials, including fossil fuels, ores, forestry and agricultural products, and many manufactured products, provides a relatively reliable basis for comparison of environmental impacts for many SMM-related activities. Combined with a realistic assessment of costs, these often-significant global

benefits (including avoided GHG, energy savings, and air and water emissions) can help clarify the benefits of SMM.

Above all, the analysis of SMM options should consider the metrics valued in the community, as well as the biggest economic and environmental impacts (which are often associated with avoided raw materials extraction). For instance, if the community is interested in reducing the costs and GHGs associated with materials management, then benefits and costs should examine dollars and tons of CO₂ equivalent, respectively.

Because it is necessary to balance multiple interactions of materials in order to evaluate SMM strategies, policymakers can turn to one or more of the analytical approaches and associated tools that have been designed to address multiple endpoints related to the environmental, social, and economic impacts of policies. These approaches fall into the general categories summarized in Table 8 below.

Table 8. Analytical approaches to support evaluation of SMM strategies^{80, 81}

Approach	Description
Cost-Benefit Analysis (CBA)	CBA aims to assign money values to all benefit and cost endpoints of a policy option so that communities or other stakeholders can compare different aspects of a project to determine whether the benefits are sufficient to outweigh or justify the costs of a policy.
Economic Input/Output Analysis (EIO)	EIOs measure the monetary value of transactions across the economy (including local, regional, or national economies). They calculate the direct and indirect impacts of changes in economic activities, and measure how changes in one sector affect other sectors (e.g., decreased demand for goods and services if employment drops). Some models also allow an analyst to combine environmental data with EIO data to examine changes in environmental impacts related to changes in economic activity.
Life-Cycle Assessment (LCA)	LCA is an approach used to calculate the environmental impacts of a product, process, or activity throughout its life-cycle; from the extraction of raw materials through production, transport, use, and disposal. LCA typically quantifies a range of environmental releases (releases of pollutants to water, air, land, etc...) and environmental impacts (toxicity, smog, climate change, etc...) associated with both the materials and energy needed to produce a product or service. LCAs provide users with a basis for comparing the material intensity and impacts of products and services.
Total Cost Assessment (TCA)	TCA is a problem-oriented methodology used primarily by businesses to capture and compare total costs (including contingent liability costs, intangible internal costs, and external costs borne by society) associated project options. TCA can be used to identify preferable materials, process designs, product designs, or capital expenditures, and can be incorporated into CBA.

All of the approaches outlined in Table 8 can be used in conjunction with, or incorporated into, the triple value framework. All of them also can incorporate the materials and energy flow analyses and other materials accounting information developed under Step 3. Rather than dictating a

⁸⁰ Organisation for Economic Co-operation and Development. "Greening Economics in the Eastern Neighbourhood." October 8, 2014. Available at: <http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?doclanguage=en&cote=env/epoc/wgwp%282007%295/final>

⁸¹ Zhang, Y. "Urban Metabolism: A Review of Research Methodologies." *Environmental Pollution*. 2013. 178: 463-473

methodology, the use of the triple value framework ensures that policy assessments and decisions account for the system interactions that can have a significant impact on environmental, social, and economic conditions in a community.

The challenge in selecting the best SMM approach for a community is considering different portfolio options of SMM practices, and comparing the benefits and costs of these SMM practices across the systems and over time. While the elements of each SMM option will reflect community-specific interests, a range of models support each of the analytic approaches outlined in Table 8, and in many cases these can provide default data about particular systems that can support a comparative approach. In addition, software visualization programs, such as Cmap, can assist with graphic depiction of systems concepts, and triple value framework programs, such as Vensim, can assist with quantitative systems modeling to help model the interactions of policies in the economic, social, and environmental setting.^{82, 83}

Table 9 summarizes for each of the seven common SMM practices, the scope, data needs, and data availability for analyzing economic, environmental, and social impacts; the table also notes key areas of intersection with other sectors that SHCRP is examining. This exhibit aims to provide a starting point for design of streamlined analytic tools that can help move communities toward effective SMM implementation.

⁸² Cmap is a software tool that allows users to map and organize multiple interactions (e.g., environmental, economic, and social interactions) in one uniform layout. More information on the software can be found at: Florida Institute for Human and Machine Cognition. "Cmap." Available at: <http://cmap.ihmc.us/>

⁸³ Vensim is a software tool that allows users to model environmental, economic, and social interactions through mathematical relationships. More information on the software can be found at: Ventana Systems, Inc. "Vensim Software." Available at: <http://vensim.com/vensim-software/>

Table 9. Overview of SMM practices, associated decision scope, key interactions, and data requirements for evaluation, and current data availability

Common SMM Practice	Scope of Decision/Flow	Key Interactions with other Systems, Practices	Critical Data Required For Analysis	Availability of Modeling Tools and Data
Recycling	<ul style="list-style-type: none"> Decision-making on materials recovery is at community level <ul style="list-style-type: none"> Waste management costs, some job, traffic impacts Regional markets/facilities for recovery may be important Environmental impacts 	<ul style="list-style-type: none"> Transportation: changes in traffic Infrastructure: recovery facilities Land use: landfill demand, planning 	<ul style="list-style-type: none"> Environmental: For target materials: quantities, per-ton recycling impacts vs. landfilling and energy recovery Economic: Costs for collection, material recovery and reprocessing and revenues from sale of recovered materials, employment in collection and processing Social: Traffic patterns (local), environmental, and human health impacts associated with externalities from recycling vs. landfilling 	<ul style="list-style-type: none"> Life-cycle inventory data are well-established for many materials <ul style="list-style-type: none"> MSW-DST, WARM, SimaPro, etc. Engineering costs, CBA methods established; specific financing options needed Local and indirect impacts from recovery are sometimes difficult to determine
Energy Recovery	<ul style="list-style-type: none"> Facilities (often regional financing, design, material flow) Utilities are key stakeholders Federal regulations affect design Energy benefits can accrue to community and operator Regional emissions 	<ul style="list-style-type: none"> Infrastructure (land use for facility and power supply) Transportation patterns will change 	<ul style="list-style-type: none"> Environmental: For target materials: quantities, per-ton recycling impacts vs. landfilling and recycling Economic: Costs for collection, material recovery and reprocessing. revenues from sale of recovered materials and energy, employment in collection and energy facility Social: Traffic patterns, environmental and human health impacts associated with externalities from energy recovery vs. landfilling 	<ul style="list-style-type: none"> Life-cycle inventory data well-established for many materials <ul style="list-style-type: none"> MSW-DST, WARM, SimaPro, etc. Engineering costs, CBA methods established; specific financing options needed Energy analysis of regional grid necessary

Common SMM Practice	Scope of Decision/Flow	Key Interactions with other Systems, Practices	Critical Data Required For Analysis	Availability of Modeling Tools and Data
Landfill Mining	<ul style="list-style-type: none"> Community-level mining Landfill operators are key stakeholders Regional/remote recovery facilities possible <ul style="list-style-type: none"> Private companies, investors may be involved 	<ul style="list-style-type: none"> Infrastructure/buildings if recovery activities are local Land use related to landfill 	<ul style="list-style-type: none"> Environmental: For target materials; quantities anticipated, byproducts, environmental footprint (energy, emissions of process) Economic: Mining, processing costs and revenues from recovered materials, employment at facility Social: Traffic patterns, environmental, and human health impacts associated with changes in landfill 	<ul style="list-style-type: none"> Life-cycle inventory data well-established for many materials <ul style="list-style-type: none"> LF-mining-specific impacts may be elusive Engineering cost data needed
Product Take-Back	<ul style="list-style-type: none"> Most often led/coordinated at corporate, national levels Communities can require collection <ul style="list-style-type: none"> Purchasing ordinances 	<ul style="list-style-type: none"> Transportation for programs 	<ul style="list-style-type: none"> Environmental: quantity, flow of targeted products, per-ton recycling impacts vs. virgin materials Economic: Transportation and collection costs to households, businesses, employment impacts Social: Changes in product availability 	<ul style="list-style-type: none"> Life-cycle inventory for recovered materials <ul style="list-style-type: none"> Processing important Costs/collection practices for project, behavioral changes
Source Reduction	<ul style="list-style-type: none"> Corporate interests typically lead and are key stakeholders Communities can implement source reduction policies, such as landfill bans (e.g., plastic bags) Regional/state support can be necessary 	<ul style="list-style-type: none"> Reduced demand for land use, transportation infrastructure 	<ul style="list-style-type: none"> Environmental: Environmental footprint of process and material that is changing, substitute materials, process emissions avoided/incurred Economic: Cost savings from source reduction, material substitution costs Social: For specific materials, avoided production- and waste-related impacts 	<ul style="list-style-type: none"> Custom modeling required; data and model availability depends on process and product changes Affects material quantities for recycling, energy recovery, etc.

Common SMM Practice	Scope of Decision/Flow	Key Interactions with other Systems, Practices	Critical Data Required For Analysis	Availability of Modeling Tools and Data
Green Design	<ul style="list-style-type: none"> Communities can require green design for buildings through codes and ordinances Corporations and national standards usual drive product design <ul style="list-style-type: none"> Community purchasing policy can support this State, federal standards may affect policies <ul style="list-style-type: none"> Transportation design is state/federal 	<ul style="list-style-type: none"> Significant interaction with infrastructure/buildings Transportation and land use may be focus of projects 	<ul style="list-style-type: none"> Environmental: Environmental footprint (GHG and other emissions) of green design production/construction and operation, compared with standard approach Economic: Cost of production/construction and operation and disposal using green design standards <ul style="list-style-type: none"> Identify changes in function, ease of use Social: Changes in use patterns, quality-of-life benefits (and costs) of design changes 	<ul style="list-style-type: none"> Green design calculators may be robust for specific practices Custom modeling necessary for specific projects, products
Green Remediation	<ul style="list-style-type: none"> Communities reap benefits, and some costs, from remediation, and govern zoning options Federal and State statutes govern remediation standards and financing options Developers, owners are key stakeholders 	<ul style="list-style-type: none"> Land use 	<ul style="list-style-type: none"> Environmental: Quantified description of changes in remediation practices, emissions, risks under project Economic: Cost of clean-up using green remediation vs. standard method, anticipated changes in remediation schedule, land use, tax implications, employment Social: Changes in use patterns, quality-of-life benefits (and costs) of remediation 	<ul style="list-style-type: none"> Custom modeling necessary for specific projects Some standard cost, benefit information available for green remediation, land use amenities and benefits <ul style="list-style-type: none"> EPA CLU-IN (Contaminated Site Clean-Up) resources

Section 5: Conclusions and Applications

As both a community-level and global strategy, SMM represents a robust, long-range approach to reducing the negative impacts of current material flows. SMM strategies aim to reduce virgin material extraction, reduce waste entering the landfill, extend the life of landfills and reduce human and environmental exposure to hazardous contaminants. These result in life-cycle reductions in energy use, water use, and emissions and also create jobs, encourage local sourcing of materials, and promote economic development. Moreover, particularly when coupled with infrastructure, building, and transportation initiatives, SMM can improve the design of communities and the quality of life offered to residents.

The current scope of material flows and current materials management in the U.S. could improve considerably as a result of more widely adopted SMM policies. Landfills can represent an inefficient and high-impact management of post-consumer materials. Corresponding extraction and use of virgin materials can represent an energy-intensive, low-efficiency option for materials production, and one with significant impacts on land use. Even the modest adoption of SMM-related practices to date has contributed to a measurable and unprecedented decrease in the per-capita use and discard of materials in the U.S. in recent years.⁸⁴

SMM can be implemented at scales ranging from private property, industrial and institutional levels, to the broader community level. Policies and incentives can facilitate collaboration with key private and public players and awareness of cross-scale factors (e.g., regional opportunities or constraints). Specific ideas that could help facilitate increased adoption of SMM include:

- Guidance for stakeholder outreach and interaction for key SMM decisions;
- Information about material quantities, composition, transport requirements, and pricing that can be used to identify market-driven incentives
- Lessons learned regarding common SMM practices and associated outcomes such as:
 - Direct and indirect effects that are captured in the triple value framework;
 - Social, economic, and regulatory contexts where the practices have been most and least successful;
 - Key barriers to implementation and any solutions found for removing them;
- Key information or data gaps that were needed to plan or implement a SMM strategy such as:
 - Costs, including engineering costs as well as social costs, revenues and cost savings, and indirect costs;
 - Key social and economic impacts, including traffic impacts, open space impacts, and employment impacts;
 - Life-cycle-based estimates of impacts on materials extraction that result from SMM strategies. While these are often global in effect, they can be significant and meaningful in community decision-making, and they are supported for many materials by readily available data.

⁸⁴ U.S. Environmental Protection Agency. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012." February 2014. Available at: http://www.epa.gov/solidwaste/nonhaz/municipal/pubs/2012_msw_fs.pdf

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