WORLD ECONOMIC FORUM

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White Paper

Circular Economy in Cities
Evolving the model for a sustainable urban future

In Collaboration with PwC

Contents

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Foreword

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The linear methods of production and consumption are unsustainable for the planet. As urbanization continues, hunger for greater resources will accelerate if the current consumption trajectory continues. For cities, this means increased waste. The linear model of “produce, use, dispose” is wasteful by design, while the circular economy is conceptualized as a continuous cycle of value preservation and resource optimization, presenting sustainable alternatives for eliminating waste.

Today, more than one-half of the world’s population lives in cities, a figure that is forecast to rise to 70% by 2050. The quality and resource rationality of cities will become an increasingly critical issue. Cities are engines of economic growth, generating approximately 85% of global GDP. They are places where people live, work, innovate, meet and consume considerable amounts of resources. Therefore cities play a pivotal part in the transition to a circular economy.

Making cities sustainable means rethinking every element of urban living. This includes moving away from practices such as landfill dumping and degenerating resources (e.g. the incineration of waste). It is, therefore, imperative that solutions are harnessed to ensure products are kept in circulation to minimize the loss of resources during the production and consumption processes.

This White Paper attempts to highlight innovative solutions applying circular principles to up-cycle waste from existing buildings, infrastructure and construction, harvest rainwater for reuse, generate clean and resource-efficient energy, treat medicinal waste, as well as procurement of goods and services.

The transition to a circular economy can only be achieved when all stakeholders – individuals, the private sector, government and civil society – collaborate. The Forum hopes that these recommendations will pave the way towards a more sustainable, liveable and healthier urban future, as well as spur additional circular initiatives in cities.

Foreword

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The rapidly urbanizing world is increasingly putting strains on the finite resources available. Current methods of production and consumption are unsustainable, and cities have a significant role to play in rethinking how they deal with waste and reinventing their supply chains. Cities are characterized by population density and the proximity of all actors – individuals, business and civil society. This provides an ideal environment in which to test and implement innovative circular economy models, which change how citizens and cities' leaders think about using and producing urban services and consuming resources.

Cities can play a pivotal role in creating an enabling environment through regulations and incentives, but the private sector needs to collaborate and explore the cross-sectoral synergies required to achieve a circular model. There are immense opportunities for public-private collaboration in achieving goals that might not otherwise be possible for cities to accomplish alone. Cities are embedding circular thinking in their procurement processes, placing the onus on the private sector to come up with new business models that are both economically viable and ecologically sustainable. This could potentially result in a situation whereby circular products and services become the new market standard. Similarly, urban-industrial symbiosis programmes can deliver greater impact in creating a resource efficient vision for a city.

This paper emphasizes the need for a multisector and multistakeholder approach for this mindset transition towards a circular economy, and the need for integrated action over the long-term in different areas of local administration. The key is to persevere with all actors in overcoming barriers that prevent society from attaining a sustainable circular future.

Foreword

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Rapid urbanization and increased consumption have led to economic growth in many parts of the world, but have also created unprecedented amounts of waste. The traditional pattern of buy-use-dispose, particularly common in cities, has packed landfills and incinerators to their capacity and compounded the need for natural resources as the demand for goods rises along with income levels. This trend is far from sustainable.

The circular economy attempts to address the dual issue of increasing waste and decreasing resources by incentivizing actors throughout the value chain to extract maximum use from both existing products and the elements within them. The flow of building materials, water, electronic waste, and even food, can be reconfigured to avoid resource waste, and urban areas offer the ideal environment to both reap the benefits and iterate on the challenges of such models. Cities around the world are already experimenting with interventions that leverage synergies across different sectors to foster symbiotic relationships in the consumption process, and as a commitment to circular economy concepts in urban planning, some have gone as far as pledging “zero waste to landfill” as a strategic goal for their city.

“Ensuring sustainable consumption and growth patterns” as specified by Goal 12 of the Sustainable Development Goals is aimed at significant waste prevention, reduction, recycling and reuse by 2030. This paper highlights solutions that are helping cities make progress in this transition, and emphasizes the importance of coordinated action from key actors – individuals, the private sector, government and civil society. Cities will have to prepare for a long-term transformation through the systematic decoupling of economic growth from resource consumption, where taking action by embracing circular concepts could lead to a more sustainable and liveable future for the next generation of urban dwellers.

The circular economy and cities

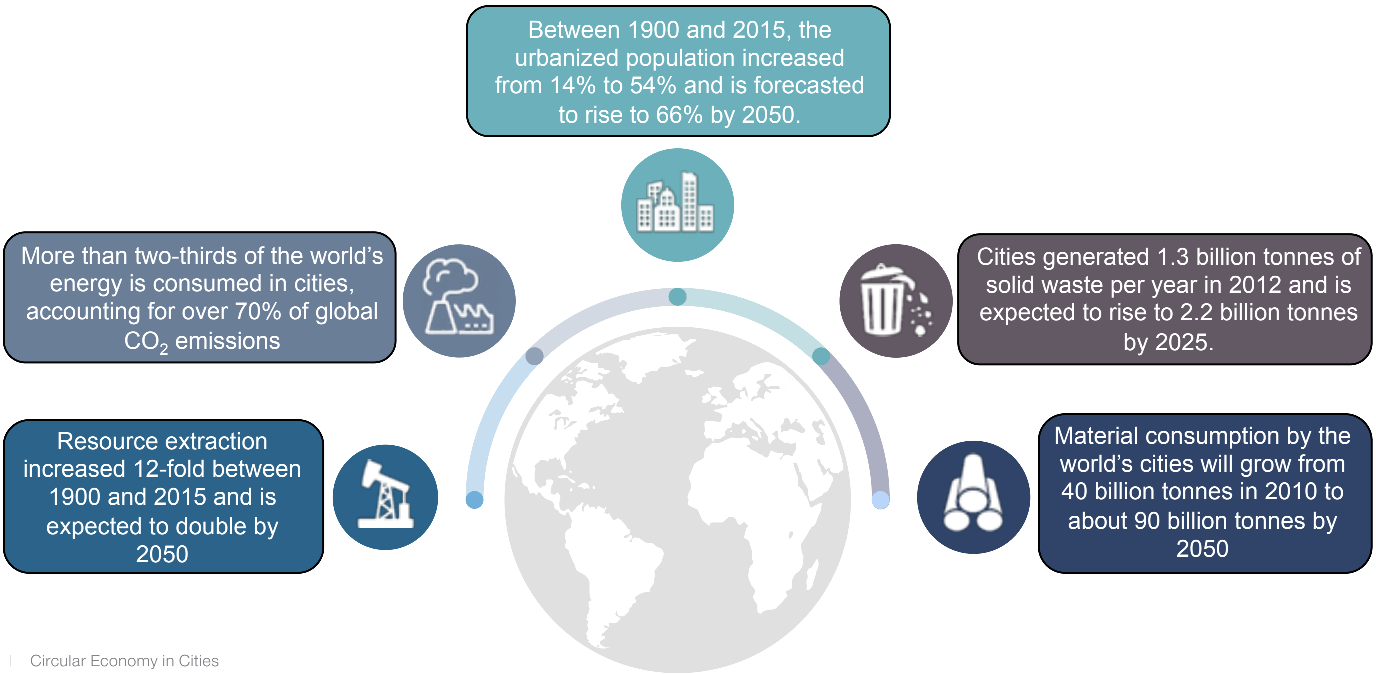
"Waste does not exist in nature, because each organism contributes to the health of the whole. A fruit tree's blossoms fall to the ground and decompose into food for other living things. Bacteria and fungi feed on the organic waste of both the tree and the animals that eat its fruit, depositing nutrients in the soil that the tree can take up and convert into growth. One organism's waste becomes food for another. Nutrients flow perpetually in regenerative, cradle to cradle[1] cycles of birth, decay and rebirth. Waste equals food."

– William McDonough, Architect, Co-Author of Cradle to Cradle: Remaking the Way We Make Things (2002) and Author of Something Lived, Something Dreamed (2003) and Positive Cities (Scientific American, July 2017)

Industrialized growth spurs urban density and increased consumption. The combined effects of urbanization, industrialization and globalization have deeply influenced the development of cities around the world. Where industrialization has driven economic growth, it has also attracted businesses and fed consumer appetites. The industrial world thrives where natural resources are available and can be extracted easily for manufacturing and production. Resource extraction increased 12-fold between 1900 and 2015. In the past 40 years alone, the global use of materials has almost tripled, from 26.7 billion tonnes in 1970 to 84.4 billion tonnes in 2015, and is expected to double again to between 170 and 184 billion tonnes by 2050 (Circle Economy, 2018b). With accelerated levels of material use, rising urbanization and affluence levels, the demand for housing, food and consumer goods is only going to surge further. According to UN estimates, between 1900 and 2015, the urbanized population increased from 14% to 54% and is forecasted to rise to 66% by 2050. This cycle of industrialized growth leading to urbanization, consumption and greater resource extraction has put tremendous pressure on the natural environment.

Cities need new ways to address waste. A quantitative analysis of global resource requirements carried out by the International Resource Panel (IRP) estimates that under business-as-usual circumstances material consumption by the world's cities will grow from 40 billion tonnes in 2010 to about 90 billion tonnes by 2050.[2] Current levels of consumption are generating unprecedented amounts of waste, which exacerbate the negative environmental effects of increased extraction. The upstream phases of resource extraction and manufacturing processes consume high volumes of water and energy (i.e. embodied water and carbon). It is estimated that more than two-thirds of the world's energy is consumed in cities, which account for over 70% of global CO2 emissions. Cities are also where the highest amount of waste is generated. According to the World Bank, cities generated 1.3 billion tonnes of solid waste per year, which translated into a footprint of 1.2 kilograms per person per day in 2012. This is expected to rise to 2.2 billion tonnes by 2025. Traditional waste management and disposal practices result in landfill sites or pollution of the environment if not well-regulated. There is a need to embrace a more viable method of production and consumption in the overall value chain to ease the burden of waste on urban areas.

The circular economy approach aims to reshape resource use by decoupling growth from material extraction. The intention is to create a more sustainable future that allows the natural environment to restore resources and protects it from the negative effects of industrialized waste.



What is the 'circular economy'?

The concept of a circular economy was conceived in the 1970s with the intention of promoting a world where nothing goes to waste. Some 40 years later, this vision has become a priority for progressive leaders and campaigners. A recent review of 114 descriptions of the circular economy analysed across 17 dimensions by Kirchherr, Reike and Hekkert has resulted in the following definition of the circular economy, reflecting a more holistic understanding:

"A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations."

The circular economy challenges the traditional, linear, "take-make-dispose" model of production and consumption, in which resources are extracted/mined/grown, manufactured, transported and then used before being disposed of at the end of the value chain. The linear model was made possible by a system where input commodities are cheap and widely available, but it is no longer sustainable, making it necessary to "close the loop" to achieve a sustainable growth model.

Circular economy — Increasing circularity — **Linear economy**

Circular economy	Strategies	
Smarter product use and manufacture	R0 Refuse	Make product rebundant by abandoning its function or by offering the same function with a radically different product
	R1 Rethink	Make product use more intensive (e.g. by sharing product)
	R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
Extend lifespan of product and its parts	R3 Reuse	Reuse by another consumer of discarded product, which is still in good condition and fulfils its original function
	R4 Repair	Repair and maintenance of defective product so it can be used with its original function
	R5 Refurbish	Restore an old product and bring it up to date
	R6 Remanufacture	Use parts of discarded product in a new product with the same function
	R7 Repurpose	Use discarded product or its parts in a new product with a different function
Useful application of materials	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9 Recover	Incineration of material with energy recovery

Source: (Kirchherr, et al., 2017)

The foundations of a circular economy have been derived from several theoretical concepts over time, and are not directly attributed to a single work or author. The concept gained momentum in the 1970s when it could be applied to modern economic systems and industrial processes, but it has evolved significantly over the past 50 years. Some of the related and connected concepts include (from more to less encompassing):

Concept	Description	Association with circular economy
Sustainable development	Sustainable development is a comprehensive concept that attempts to reconcile and combine three dimensions of development: economic, environmental and social.	Sustainable development connects with the circular economy through the economic and environmental dimensions, as well as through corporate social responsibility, business's entryway into sustainable development.
Green economy	The green economy is a concept that proposes economic solutions to mostly environmental issues through large, multipartite policy proposals emanating from the United Nations and trickling down through national governments and NGOs.	The green economy overlaps with the circular economy in that both concepts leverage economic activities in order to attain sustainability.
Performance economy	The performance economy (also known as the functional economy) is one of the main DNA strands (along with cradle-to-cradle and industrial ecology) of the circular economy. Its thesis dictates that in order for business to decouple growth from resources consumption, new business models based on selling service (or performance) rather than goods in quantity, and with retained ownership, must be adopted. This general idea can spur innovation and create incentives to close production and consumption loops.	The performance economy is one of the main pillars of the circular economy, demonstrated through the focus on longevity and intelligent waste-as- input management, powered by innovation and new business models.
Life cycle thinking	Life cycle thinking (LCT) is closely tied with life cycle assessment (LCA) and life cycle management (LCM). Its main goal is to reduce environmental impacts through an ISO landmarked, eco-efficiency-based methodology, which looks at each step of the product, process or service's life cycle, in order to design or redesign these for lower systemic impact.	Life cycle thinking (including LCA and LCM) is based on systems thinking mostly applicable at the value chain concept level. It is steeped in relative sustainability assessment (i.e. impact assessment based on hotspot identification), while circular economy is based on absolute sustainability assessment (ASA).[3]
Cradle-to-cradle thinking	Cradle-to-cradle thinking champions eco-effectiveness (and dismisses eco-efficiency)[4] through an approach based on cycling technical nutrients (such as durable goods made of plastics or metals) and biological nutrients (such as consumption products like food) in order to achieve healthy material metabolisms (such as industrial symbiosis programmes).	Cradle-to-Cradle thinking was developed by William McDonough and Michael Braungart and is a design framework that includes the Circular Economy. It entails a circular paradigm to achieve total recycling through product design (or redesign). The products are designed for recycling with safe and healthy materials in "use cycles" to enable and optimize the Circular Economy. In the early 1990s McDonough and Braungart introduced their approach to the concept of biological and technical "products as a service".
Shared value	Shared value is a management approach that was developed by strategy authorities Michael Porter and Mark Kramer in order to reconcile capitalism with societal needs. The framework calls for businesses to create value by identifying and addressing social needs through new products and markets, redefined value chains and the creation of community development clusters.	Shared value endeavours to map out the intersection between evaluative approaches and business strategy for profit making. Both shared value theory and circular economy concepts rest on the idea that the economy needs to be overhauled and decoupling mechanisms need to be introduced for business and consumers to continue to thrive; however, circular economy theory calls for greater disruption.

Industrial ecology	Industrial ecology is a research and application field focused on the creation and maintenance of a closed-loop industrial ecosystem. Industrial ecology aims at optimizing energy and materials, pollution and waste reduction through an economically viable transformation of industrial byproducts or waste into inputs, with the ultimate goal of enabling industrial systems that mimic natural ecosystems.	The application scope of industrial ecology is based on the association of multiple companies within an industrial ecosystem. It coincides with circular economy thinking on taking a systems approach to resource efficiency in terms of circularity.
Extended producer responsibility	Extended producer responsibility (EPR) is a condition of the "polluter pays" principle and aims at shifting a product's environmental responsibility over the full life cycle back towards the producer (and away from municipalities). Even though EPR has the potential to drive change over the full life cycle, it has mostly enabled post-consumer end-of-life management.	Extended product responsibility is a strictly defined business concept whose applicability is focused within a single company. It consists of the first attempt at a systematic closed-loop system with a private actor focus, primarily based on systems thinking to "design out waste" by an individual producer.
Ecodesign	The concept of ecodesign is based on integrating environmental aspects into product development. Ecodesign can be used as a tool to implement LCA results or it can be a guideline, a checklist or an analytical tool that supports an eco-efficiency-based product development process.	Ecodesign is a tool that aims to implement environmental considerations into product design and is often used in conjunction with LCA.

Source: (CIRAIG, 2015)

The circular economy principles

Originally, environmental design philosophies focused on selecting recyclable materials for product development. Today, this has evolved to include the radical redesign of products and services around ecological, economic and social considerations for a sustainable future. Sustainable use of raw materials, closed-loop manufacturing and production processes, adoption of sustainable methods of consumption, and the development of more extensive commodity markets for keeping products in use have all become essential parts of being circular.

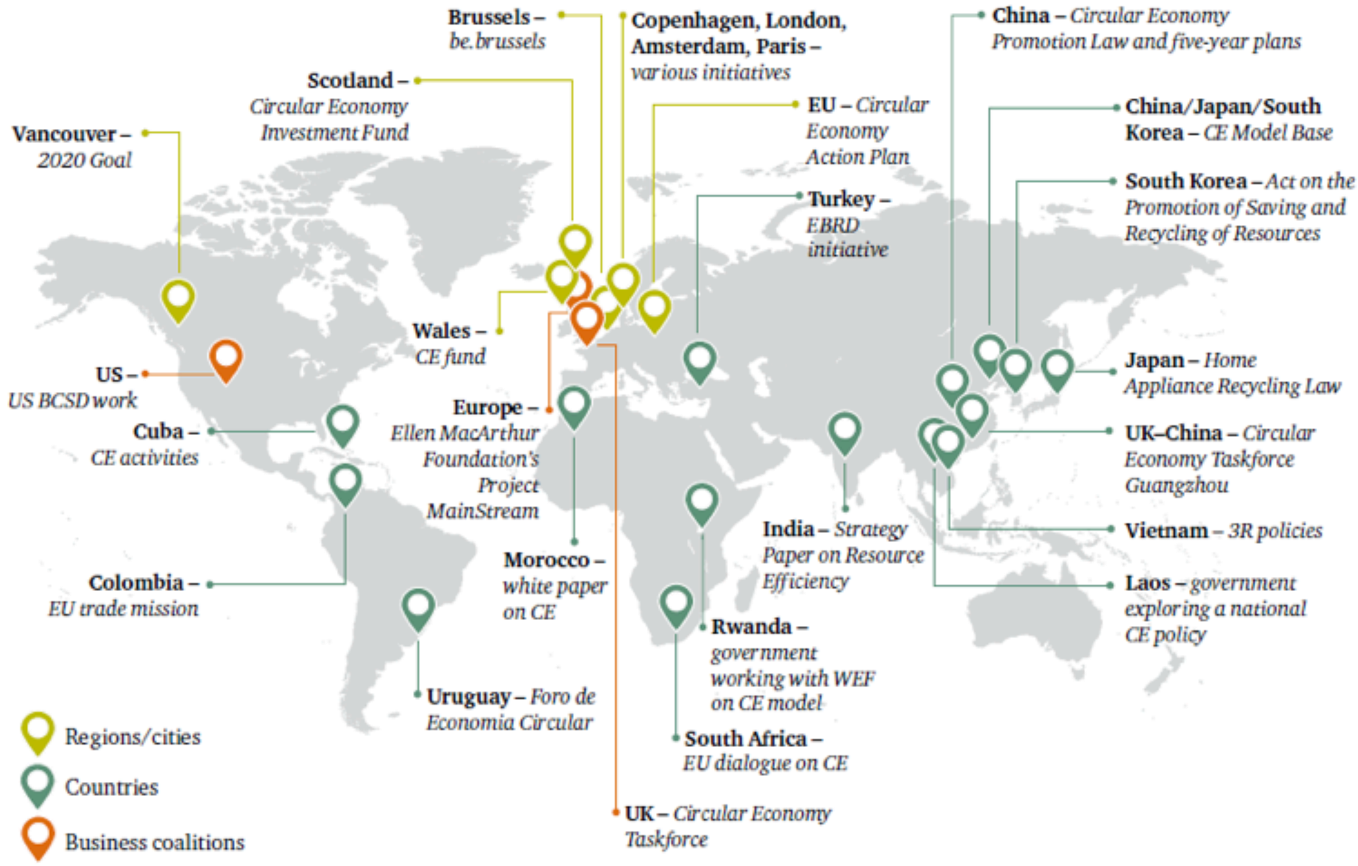
With regard to material and process flows, the circular economy concept can be visualized through two dimensions. Upstream circularity (before use) concerns managing resources efficiently, improving productivity in production and consumption processes, minimizing waste, and keeping product costs as low as possible. On the other hand, downstream circularity (after use) concerns preserving the value remaining in otherwise "waste" materials, and maximizing the extraction of that value within the system. For example, keeping used products out of landfills by recovering and reintroducing their useful components back into the economic flow as an input. The Ellen McArthur Foundation, which leads the thinking on circular economy concepts, has underpinned three principles characterizing the circular economy:

- **Value preservation –** implies maintaining the highest possible value from input materials in production processes and final products. This involves repurposing, remanufacturing, refurbishing, repairing and reusing components, product life extension, and product value extension.
- **Resource optimization –** implies limited, efficient and lessened use of primary resources combined with improved waste collection, resource recycling, energy recovery from material incineration and use of renewable energy sources.
- **System effectiveness –** implies minimizing systematic leakage of that which is useful to humans (e.g. food, shelter, health, education) during the production/consumption cycle and addressing externalities (e.g. land use, air, water and noise pollution, climate change).

Cities are key to going circular

More than 80% of global GDP is generated in cities, which therefore makes them ideal testing grounds for circular economy models. The confluence of business, resident and government actors creates live innovation labs for addressing the complex challenges of linear economic models. The rich ecosystem of producers, consumers and intermediaries, as well as the goods themselves and the constant flow of information, create an opportunity to introduce new practices, including facilitation of the reverse logistics sector, material collection, waste processing, energy and natural resource conservation and new business models and product design that incorporate circular thinking.

Densely populated cities operate in a resource-constrained environment where implementing circular practices can result in immediately visible benefits, such as cost savings in the private sector. Further, the pragmatism and physical proximity in cities makes it easier to implement policy changes than at a state or national level, where bureaucratic structures and legislative timelines can hamper institutionalizing novel circular concepts. Therefore, cities can be more agile and adaptive when implementing pilot initiatives, allowing them to stimulate change faster.



Source: (Preston & Lehne, 2017)

Transitioning to a circular city: Defining a vision

According to the Ellen MacArthur Foundation, a circular city embeds the principles of a circular economy across all of its functions, establishing an urban system that is regenerative and restorative by design. In such a city, the idea of waste is eliminated, with assets kept at their highest levels of utility at all times and the use of digital technologies a vital process enabler. A circular city aims to generate prosperity and economic resilience for itself and its citizens, while decoupling value creation from the consumption of finite resources.

Amsterdam, one of the leaders in the application of circular economy concepts to city governance, follows seven principles in its transition towards a circular economy, as elaborated in a report commissioned by the city government. These principles can be extended to define a vision and an action roadmap on circularity in cities:

- **Closed loop –** all materials enter into an infinite cycle (technical or biological).
- **Reduced emissions –** all energy comes from renewable sources.
- **Value generation –** resources are used to generate (financial or other) value.
- **Modular design –** modular and flexible design of products and production chains increases adaptability of systems.
- **Innovative business models –** new business models for production, distribution and consumption enable the shift from possession of goods to (use of) services.
- **Region-oriented reverse logistics –** logistics systems shift to a more region-oriented service with reverse-logistics capabilities.
- **Natural systems upgradation –** human activities positively contribute to ecosystems, ecosystem services and the reconstruction of "natural capital".

Source: (Circle Economy, TNO and Fabric, 2016)

A circular city encourages the use of systems thinking to provide economic, social and environmental benefits for its citizens, while also looking to improve the quality of life.

Drivers of circular economy trials in cities

Growing awareness that the linear model has resulted in the over-exploitation of materials and increased pollution levels is fuelling demand for responsible products. The Sustainable Development Goals for 2030 encourage nations to consider circularity and leading cities to experiment with innovative circular ideas and methods, driven by their unique social, cultural, economic, technological or regulatory contexts. Drivers of cities' interest in circular solutions include:

- **Urbanization –** as urban areas expand, infrastructure and services put growing strain on the environment as limited resources must by stretched to accommodate greater activity and population.
- **Supply and price risks –** urban economies can be vulnerable to disruptions in the supply of virgin raw materials, and to high and volatile prices. Circular practices can mitigate this risk by developing trade for input components.
- **Ecosystem degradation –** most waste (solid, liquid, organic and hazardous, including construction and demolition waste) ends up in landfills, an excess of which has further burdened ecosystems already degraded by climate change, loss of biodiversity, land degradation and pollution.
- **Environmental accountability –** businesses and governments are increasingly aware of intensified demands for accountability, and the reputational threat to brands from an adverse ecological footprint.
- **Consumer behaviour –** hyper-consumerism results in products being disposed of before their full value is extracted, increasing pressure on waste-removal processes, which can be mitigated by new business models (e.g. product as a service, collaborative consumption). Experimentation with such models in transportation and hospitality is increasing interest in their applicability to other sectors.[5]
- **Advances in technology –** digital platforms are enabling circular economy principles to be applied on a larger scale by improving access to information, management of materials, tracking and logistics, transparency and accountability, facilitating deployment of innovative circular solutions.

The circular economy advantage

The transition to a circular economy requires rethinking market strategies and models that encourage competitiveness in different sectors and the responsible consumption of natural resources. This would entail changing consumer behaviour, regulating production processes, generating new avenues for employment and reducing demand for new raw materials.

The circular economy could enable:

- creating a circular supply chain, in which residual outputs from one process feed into another process
- recovering the resource value of materials in a manner that creates new value from these same materials
- extending the work life of a product and encouraging access and retaining ownership
- improving the usage rates of products through shared use.

All stakeholders stand to benefit from products being conceived with sustainability in mind – making them more capable of being repaired or reused, and with better traceability to determine whether raw materials have been sourced sustainably:

- **Citizens –** apart from reducing their ecological footprint, citizens can benefit economically from the extended lifespan of products. If they buy assets, they can generate revenue from unused or underused capacity. Alternatively, product-as-a-service models, in which customers pay for function or performance instead of taking on product ownership, spare the user maintenance, storage, repair and end-of-life costs.
- **Businesses –** the circular economy brings opportunities to expand into new areas such as collection and reverse logistics, remarketing, component remanufacturing and refurbishment. Reducing use of virgin material reduces exposure to price volatility and supply shocks due to natural disasters or political imbalances. Implementing circular economy concepts promotes wider re-evaluation of supply chains, which can lead to improved resilience. Product-as-a-service models entail long-term relationships between customer and supplier, giving more opportunity to build customer satisfaction and loyalty as well as improving brand reputation through sustainable practices (Ellen MacArthur Foundation, 2015).
- **Governments –** the circular economy decouples economic growth from resource consumption, enabling cities to achieve prosperity while minimizing negative environmental impacts from landfills or incinerating waste. This can create jobs in areas such as high-quality recycling and repair practices and logistics.

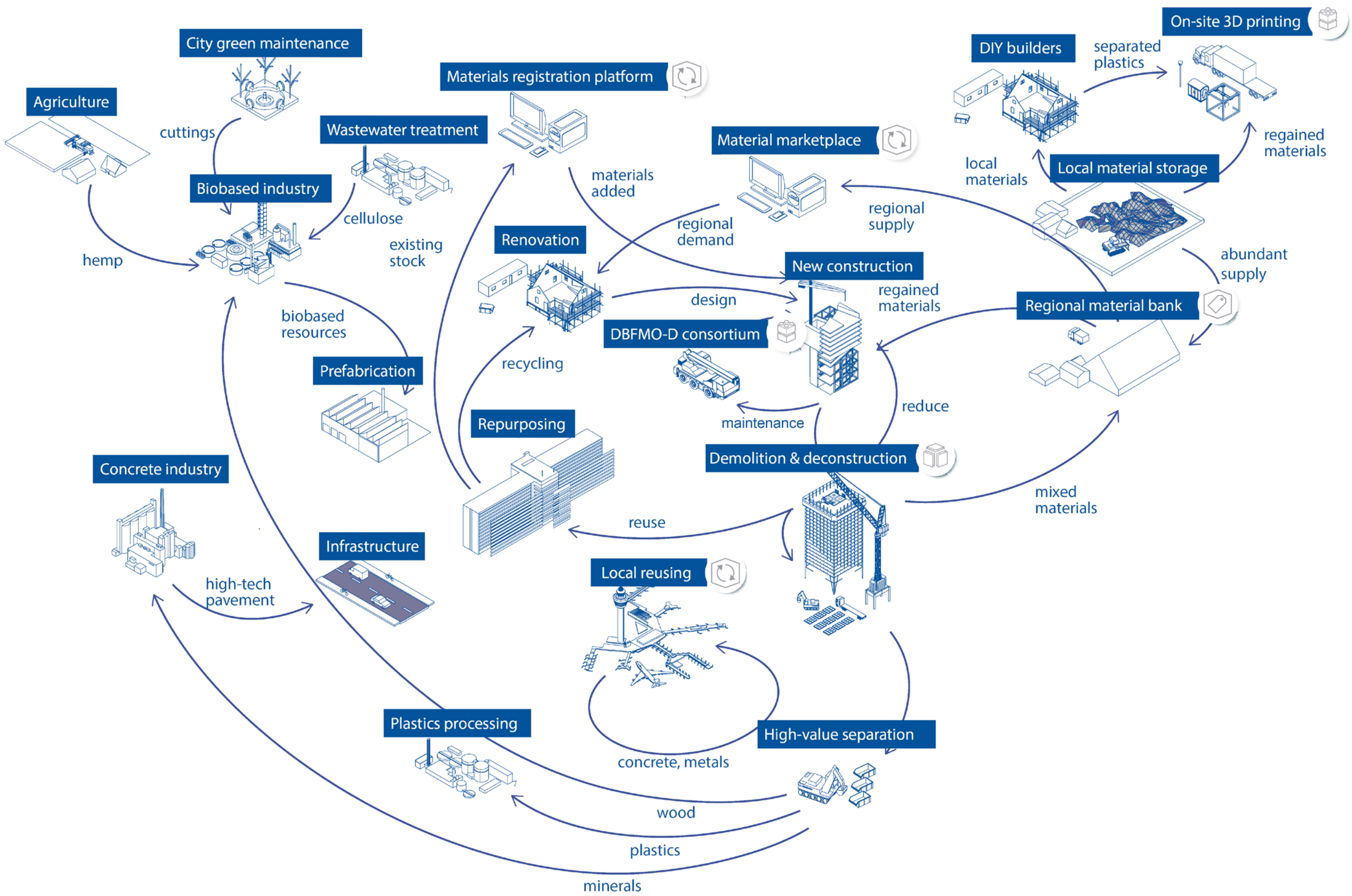
Opportunities for the circular economy in cities

Cities are taking opportunities to improve efficiency and environmental impact by embedding circular economy principles in urban infrastructure and services, from mobility to energy to healthcare. This section explores opportunities in key sectors.

Channelling used building materials to new building sites

With growing urban populations comes the need for cities to build more infrastructure: 75% of infrastructure required by 2050 is not yet in place today (Global Infrastructure Basel) and $41 trillion is the estimated cost of refurbishing old and building new urban infrastructure only through to 2030 (International Resource Panel, 2013). Building materials account for around 40–50% of an office building's carbon footprint (producing cement and steel accounts for nearly 80% of energy used during construction), with the remainder going towards transporting materials, removing waste and using energy on-site (Circle Economy and Ecofys, 2016). If the construction sector continues to use traditional methods, it could devastate the environment, atmosphere, natural resources, health and the economy. Therefore, cities need to provide incentives to builders to take a more holistic systems approach to the design, construction, maintenance, operation and after-life use of buildings.

The figure below visualizes material flows in the construction sector. Multistakeholder collaboration between city municipalities, the construction and waste industries, building owners, innovation agencies and universities can effectively begin to map such flows of construction resources throughout a city, improving the ability to anticipate future availability of resources and move towards being more self-sufficient and circular.



Source: (Circle Economy, TNO and Fabric, 2016)

Buildings can and should be designed to reuse or repurpose materials up to their maximum lifespan. Using "material passports" whenever a building is constructed – listing the quantity and quality characteristics of all materials used – can stimulate recovery, recycling or reuse when the building is ultimately demolished. With more integrated planning of construction and demolition projects, used material can feed into new buildings. Online marketplaces and databases can link buyers to used materials from demolition sites, as well as creating new jobs in cataloguing the materials; mechanisms of supply chain cooperation[6] and financing can also contribute. Meanwhile, new production techniques such as 3D printing and pre-fabrication can facilitate modular design that makes buildings more multifunctional, optimizing the use of space and increasing the chance that a building can later be repurposed rather than demolished and replaced.

Material passports are being used by Buildings As Material Banks (BAMB), a Horizon2020 project funded by the European Commission, along with reversible building design – as the name suggests, a design approach that enables buildings to be easily deconstructed, or where parts can be removed and added without damage. Six BAMB pilots are testing and refining new business models, policy propositions, and management and decision-making tools, enabled by technologies such as building information modelling (BIM) to optimize structure and radio frequency identification (RFID) to identify materials used. BIM creates a detailed 3D model of a building with information attributes such as location, size and composition of materials used, which passes from architect to contractor to owner and improves the efficiency and economic viability of later decommissioning or retrofitting. Together with the use of RFID tags on building materials, to help track and trace items at different stages of the building life cycle, BIM opens up new avenues to develop material banks (Barrie, 2017a).

Case study: City town hall as a raw material depot – Brummen, the Netherlands

The city of Brummen was not certain whether it would still need a town hall in 20 years, as current national policy was moving towards aggregating Dutch municipalities into larger administrative units. Rau Architects proposed a design for an extension to the town hall that could easily be disassembled, using high-quality construction materials to guarantee circularity at the end of the contract period. With limited use of concrete, the facade and floors are made from timber in prefab components which can easily be dismantled and reused. The building is, in effect, not only a town hall but also a raw materials depot.

Source: (Guldager Jensen & Sommer, 2016)

Although construction and demolition waste cannot be completely avoided, they can be looped back into production. For example, the South African company Use-It makes environmentally friendly bricks for affordable housing from waste soils and rubble that would otherwise go to into landfill, and a consortium of architects in Australia are designing a 49-storey (200m) superstructure that instead of demolishing the existing building on the site, will reuse 98% of the bearing structure and upcycle two-thirds of the materials – saving the CO2 equivalent to 10,000 flights between Sydney and Melbourne. The project aims to be a proof of concept for circular building in high-rises (Mousa, 2017) and (Danish, 2017).

Case study: Using materials from abandoned buildings – Lolland and Copenhagen, Denmark

The existing building mass holds an untapped potential for extracting materials for use in new buildings. Across Denmark, abandoned homes and commercial buildings lie ready for demolition. In the rural area of Lolland the population is decreasing, leaving old buildings uninhabited. These buildings are now being seen as resources rather than waste. In a project with the municipality of Lolland, Lendager Group has mapped materials and potential opportunities (providing jobs and resources to the local community) by demolishing the abandoned buildings and recycling their materials. In the Danish capital, Copenhagen, where demand for housing is high, Lendager Group is also working to improve the sustainability of new buildings. By using recycled materials for new buildings the CO_2 footprint can be reduced by up to 70% compared to traditional building methods. Lendager Group has invented a new technique of upcycling brick walls of old buildings ready for demolition. The strength of the mortar makes it impossible to recycle individual bricks so instead the walls are cut out in modules for new building façades. The Resource Rows in Ørestad, Copenhagen, will be the first residential housing area build with upcycled brick modules from abandoned buildings.

Source – Lendager Group contribution to World Economic Forum Study

Water harvesting and reuse

From Mexico City to Sao Paulo, Los Angeles, Lima, Cape Town and Sana'a (Yemen), many cities have already experienced severe water shortages primarily driven by rapid urbanization and/or climate change. According to the United Nations, nearly half of the world's population could suffer water stress by 2030. While municipal withdrawals account for only about 12% of total water withdrawals[7] (UNEP, 2015), cost and quality concerns limit the reuse of water used for domestic needs such as washing, bathing, cleaning, drinking, toilet flushes and landscaping. The challenge is to harvest and reuse water as much as possible before releasing it back into the natural systems, using clean energy.

Rainwater harvesting is a traditional form of storing water for reuse, deployed in cities across the world. In Tokyo, each building must have an underground rainwater tank that feeds into the water system. In Copenhagen, another Resource Rows initiative reuses rainwater collected from solar cells and other unused "clean" roof surfaces for toilet flushing and irrigation, promising considerable economic savings on utility costs for the residents (Lendager Group, 2017).

Case study: The sponge cities initiative – China

China's "sponge city" initiative is a joint effort by three ministries – housing and rural-urban development, finance, and water resources – to tackle rainwater runoff, which is exacerbating pressure on groundwater. Projects in 30 cities – including Shanghai, Wuhan and Xiamen – total $12 billion in funding, with the central government covering 15–20% of costs and the remainder covered by local governments and private developers. These incorporate features such as wetlands and bioswales[8] – which naturally help absorb water – plant-covered rooftops and permeable pavements. While the initiative has had to resolve some challenges such as pollution of groundwater and the sourcing of necessary materials, it aims to have 80% of China's urban areas absorbing and reusing at least 70% of rainwater by 2020.

Source: (Biswas & Hartley, 2017) and (Garfield, 2017)

Cities can also explore circular practices to improve efficiency by reducing water leakage from supply systems: every day, the US loses 7 billion gallons of water through leaky pipes, and in developing countries, lost water is valued at more than $3 billion per year (The World Bank, 2016). Advanced metering infrastructure (AMI) networks can improve efficiency by detecting these leaks early and sending real-time alerts, but these require centralized implementation and investment. Encouraging citizens to consume wisely is another approach – for example, by charging directly for the amount of water consumed, banning certain activities, such as washing cars, under extreme circumstances, and mandating installation of super-efficient water systems; as well as subsidizing or giving away replacement fixtures and other water-saving products (Barrie, 2017c). Furthermore, the water system itself can be made circular by generating hydroelectric power in hilly areas and using wastewater treatment to generate electricity: using technologies such as hydrolysis or gasification, sewage treatment plants can cover up to 60% of their own energy demands (Barrie, 2017c). One cutting-edge technology is Ecovolt, developed by Boston-based Cambrian Innovation – a novel bioelectric process that simultaneously treats water and generates biogas energy.

Circularity through reduced energy use

From wastewater to construction to street lights, energy systems are vital to urban infrastructure – and the demand for energy will only increase as urbanization grows. In the EU, buildings use more energy than any other sector, accounting for roughly 40% of primary energy consumption and 36% of CO_2 emissions (Europa, s.d.); the situation is similar in the United States, where commercial and residential buildings consume about 40% of all the energy the country produces. According to carbon data from C40 cities, 29% of city buildings' emissions are associated with the supply of electricity (C40 and Arup, s.d.).

Circularity in energy systems – which encompasses the entire supply chain, from generation to storage, transmission, distribution and consumption – is vital to meeting the Paris Climate Agreement (COP21) goal of reducing emissions to a level that would limit global temperature rise to 1.5°C. Current climate policies still leave a gap, and it is estimated that circular economy strategies can mitigate this by about half (Circle Economy and Ecofys, 2016).

By 2015, renewables constituted 23% of global energy consumption – and cities across the world have pledged to move towards cleaner sources of energy as part of the COP21 agreement. In the US, Las Vegas municipal buildings run entirely on clean energy (solar and hydroelectric). In Germany, Munich is aiming for 100% supply from renewable sources by 2025 and is compelling utility companies to source only from renewable sources. By 2050, Barcelona is looking to become energy sufficient and Frankfurt is implementing a masterplan to go 100% renewable.

Smart energy grids are enabling more efficient energy distribution through real-time communication between energy generators, utility companies and consumers. New models are emerging that aim to improve efficiency by decentralizing energy exchange between buyers and sellers: Transactive Grid, a start-up based in New York, is using blockchain to record the energy generated by rooftop solar panels; Grid Singularity, based in Vienna, Austria, is working to decentralize energy markets in developing countries; MIT start-up SolarCoin pays people with an alternative digital currency for generating solar energy (Rutkin, 2016).

Some studies suggest electric vehicles will play a critical role in how cities implement smart grids through vehicle-to-grid (V2G) technology, which allows electric vehicles to charge and discharge electricity to and from the grid, improving the power system's resiliency and reliability by providing a buffer to the intermittency of supply from renewable sources(Barrie, 2017b). The car manufacturer Nissan is among those involved in testing V2G systems.

Electronic waste in cities

Rapid innovation in information and communication technology has led to rapid obsolescence – particularly of end-user devices. Replacement cycles are shorter. Owning more than one device is common. With increased disposable incomes in developing countries, more people are able to spend on electrical and electronic equipment. This all generates more e-waste, especially in cities (Baldé, et al., 2017). According to the Global E-waste Monitor report, the world generated 44.7 million metric tonnes of e-waste in 2016 – the equivalent of 4,500 Eiffel towers – including around 435,000 metric tonnes of mobile phones.

In some cases, there can be commercial value in collecting assets at the end of their first life to sell the devices themselves or recover viable parts and discrete materials through disassembly. The UK's Mazuma Mobile (now part of EcoRenew) pays cash for old phones and refurbishes them for resale in the UK and emerging markets such as China and Africa, recycling materials from phones that cannot be reused. However, the value of precious metals and plastics in each phone – around €2 worth – is not sufficient to encourage robust recycling schemes on a large scale; circularity depends on a secondary market and devices being designed for longer lifespans (Baldé, et al., 2017). Fairphone, an Amsterdam-based smartphone producer, increases the lifespan of its products by designing them to consist of seven modules, each of which can be repaired or replaced without the need to return the entire device. In its smartphone-as-a-service model, users pay Fairphone a fixed monthly fee rather than buying or leasing a specific phone (Circle Economy, 2018a). In another example, as part of its circular economy programme, Cisco is piloting an improved, fast and easy collection process called Send IT Back. Cisco has been offering product trade-in and free takeback of used gear for more than a decade, but return rates have been relatively modest. With increased, used-Cisco-product return rates, subscription-based business models, as well as closed loop return of material back to manufacturing, become more scalable and self-sustaining.[9]

As market incentives are often insufficient to guarantee recycling, cities need to also consider a regulatory approach. The Japanese Home Appliance Recycling Law resulted in the Panasonic Eco Technology Center (PETEC) developing technology to sort three major types of resin – polypropylene, polystyrene, and acrylonitrile butadiene styrene – and remove hazardous substances during sorting. It has so far recycled over 11 million products (techUK, 2015).

Case study: Recovering used IT assets – cities closing loops by working with the private sector

When a product is more complex, it is likely that the original manufacturer (OEM) is able to harvest the most value at the end of the product's initial use cycle. The OEM is likely to be best placed to service the product during its initial use cycle as well as remanufacture and resell with any necessary product updates with a full warranty. The OEM is also better able to harvest components or commodities for reuse in service operations or in new product manufacture. Return logistics and processing are an important cost consideration, but typically have not been an impediment to the collection of used gear. What is challenging is reaching and educating the hundreds of thousands of customers around the world and changing behaviour to promote return to the OEM.

Cities could provide a boost to product return by centralizing the collection of many used products. Reflecting urban density and scale, it is more cost-effective to collect and segregate equipment by vendor, transferring the collected products to OEMs, who would pay for such city services. This type of model would be relatively cheap to pilot and could be used in many sectors (e.g. IT, household goods, clothing). A challenge is to not think of this collection as another form of municipal waste collection. Used goods and material must be handled like new product (rather than rubbish) to avoid losing value through damage or contamination. This new perspective is an outcome of the change to a circular economy.

Another challenge to product return is that regulatory and/or tax hurdles, generally created at the national or regional level, often impede the cross-border movement of used goods. The current regulatory regime needs to be updated to classify used product moving from a customer back to the OEM the same as new components or products being shipped in the forward supply chain. There should also be a rebate or adjustment to country producer product waste and packaging levies based on the amount of gear each OEM receives from its customers and removes from the country or regulatory jurisdiction.

Source – Based on input from Darrel Stickler, Global Environment Lead, Cisco

Circular solutions to urban healthcare

Circular economy principles can make healthcare more affordable and accessible. Sharing platforms such as Warp It in the UK and Cohealo in the US are making optimal use of surplus medical equipment, including MRI and CT scanners. The product-as-a service business model – in which hospitals pay for the use of medical equipment, rather than buying it – could incentivize manufacturers to optimize design for reusability. However, it would currently be challenging to apply this model to the developing world due to inadequate infrastructure for repair, maintenance and safe disposal of expensive machine components.

Case study: Reprocessing medical waste – Intermountain Healthcare

The Performance Certified HARMONIC® Program sterilely reprocesses medical devices to the original equipment manufacturer standards, so they can be reused. Working with partners such as 3M and Philips Healthcare, Intermountain Healthcare has identified 800 items from areas like cardiovascular, orthopaedics, general surgery and nursing care that can be reprocessed – with an additional 350 being evaluated. Items are marked each time they are used, and some can be reused as many as 20 times before being sent for recycling, both for plastic and metal parts. The programme diverted 186,476 items, weighing 37 tonnes, from landfills in 2017. The biggest challenge is getting FDA approval, which also requires other healthcare providers to be on board.

Source: Intermountain Healthcare contribution to World Economic Forum study

Circular solutions could also apply to medicinal waste, defined by the World Health Organization as "expired, unused, spilt and contaminated pharmaceutical products, drugs, vaccines and sera". Most unused medicines are disposed of in household bins, and could contaminate the water supply by seeping out of landfills. Bringing them back into distribution could help reduce costs to public health systems and reduce the carbon footprint of manufacturing, when the logistical costs of reuse processes (collecting, dispatching, quality checking, repackaging and redistributing) are substantially lower than the value of the medicines. However, this would depend on meeting safety concerns around inadvertent contamination, deliberate tampering, use of counterfeit drugs or improper storage conditions. In Coimbatore, India, members of the Inner Wheel Club – a women's voluntary organization – have a collection box where people can drop their leftover unused, unopened and unexpired medicines. Members collect the drugs, sort them with the help of a pharmacologist and hand them to people in need at homes for the elderly (*The Hindu*, 2018).

Organic waste, including food

Significant amounts of land, water and energy are consumed in growing and processing food that goes to waste –ending up in landfills and releasing methane, which exacerbates greenhouse emissions – while 815 million people were undernourished in 2016 (Food and Agricultural Organization, 2017). Circular approaches to food waste are logistically complex because food is perishable. However, food that is unwanted but still edible can be donated: in 2016, France became the first country to require supermarkets to donate unused food instead of throwing it away. France also requires companies to report statistics on food waste and restaurants to make takeaway bags available (Hinckley, 2018).

Organic waste can be collected and treated with solutions ranging from community composting to large-scale anaerobic digestion. Adelaide composts 70% of its organic waste. San Francisco distributes 600 tonnes of composted organic waste per day to local farmers and gardeners who grow produce to sell in the city (Barrie, 2017d). New York has distributed educational materials to encourage household composting and has set up drop-off sites for community composting (Ellen MacArthur Foundation, 2017b).

Case study: Recycling the 'unrecyclable' – TerraCycle

TerraCycle collects hard-to-recycle post-consumer waste for repurposing, from cigarette butts in Tokyo to chewed gum in Mexico City and dirty nappies in Amsterdam, via various models funded by brands, consumers or government. It has made playgrounds in Philadelphia from oral care waste, community gardens in New York City from beauty care products waste, and exercise pavilions in London from deodorant waste. In 2017, it partnered with Rubicon Global to combine waste solutions for both sets of customers in a wide range of services that move towards zero waste. It is providing its customers, including cities, with non-landfill solutions for waste ranging from common recyclables such as mixed recycling and cardboard to harder-to-recycle streams such as confectionery wrappers and cigarette butts. It is now working with partners to redesign disposable packaging to become ultra-durable and industrially refillable, in a program called "Loop" scheduled to launch in January 2019.

Source: TerraCycle contribution to World Economic Forum Study and (Rubicon Global, 2017)

In another innovative approach to circularity, Local Loop Farms in Kalamazoo, Michigan, are closing the loop in food production using aquaponics – a combination of aquaculture and hydroponics, in which food waste is used to cultivate flies, which become food for fish for human consumption, while waste from the fish is used as a fertilizer to grow produce. Technologies such as aquaponics and hydroponics can reduce water usage by 90% and are ten times more productive per square metre compared to traditional growing methods (Barrie, 2017d).

Plastic waste

More than 40 years after the launch of the first universal recycling symbol, only 14% of plastic packaging is collected for recycling (Ellen MacArthur Foundation, 2017a). Low rates of collection, reuse and recycling cost the economy $80–120 billion annually. Coupled with inefficient disposal methods, they are also leading to far-reaching environmental, health and social impacts as plastics leak into natural systems. Improvement efforts have so far been fragmented. Scalable impact will require an after-use plastics economy that decouples plastics from fossil feedstocks, increases the quality and quantity of plastic for upcycling, and encourages adoption of reusable packaging including industrially compostable plastics.

Recycled plastic is now being used in roads: Scotland-based start-up MacRebur makes road asphalt out of plastic waste, which it claims is 60% stronger than standard asphalt. VolkerWessels, a construction services firm from Holland, is working on recycling plastic waste into lightweight, prefabricated modules with hollow interiors that can be fitted with cables and plastic pipes and allow excess water to drain, minimizing the risk of subsidence and making roads last three times longer (*Gulf News*, 2017). Methods of converting plastic waste into fuel or chemicals (waste valorization) can also aid in diverting waste from landfills; however, the efficiency levels and environmental impact of such initiatives would be critical in determining where these solutions are closing consumption loops without the toxicity introduced by plastic waste.

Case study: Waste recycling in India

Indian cities face tremendous challenges in segregating waste. In Mysuru, India, citizen awareness programmes have helped cities segregate compostable from non-compostable waste, with reusable items such as bottles, metal, footwear and plastic cups being sold to scrap dealers, and the remainder being composted and sold to farmers. A quarter of the 402 tonnes of waste produced by the city each day is processed this way, with about 70% of the costs covered by the sale of fertilizer, and the rest covered by central government subsidies, property tax and a fee on residents.

India also has a thriving informal recycling sector – but it is inefficient, with a fragmented value chain and unscientific processes. About 10 million tonnes of discarded plastic make it into recycling streams each year, but over 80% is downcycled into potentially contaminated low-value products, losing $1.8 billion in value. Banyan Nation, a waste recycling start-up (and winner of the World Economic Forum's The Circulars 2018 Award), is trying to integrate and formalize this value chain, while devising technology innovations to decontaminate discarded plastics. Banyan's recycled plastic known as "Better Plastic" has been tested and certified by brands such as Tata Motors and L'Oréal for use in mainstream products such as bumpers, shampoo bottles etc. In addition to developing an India first cleaning technology to remove paints, inks and other contaminates from plastic, the company developed a data intelligence platform to integrate a highly fragmented and informal supply chain. The platform has been extended to help cities manage their waste more effectively and today the state of Telangana has signed memorandums of understanding with the company to adopt the platform across the state. The platform allows city authorities to get a bird's-eye view of the waste management operations and leverage from data analytics in converting an offline, adhoc and reactive system to being online, predictive and real time system. In the long run the platform can help policy-makers and cities establish and develop innovative models for integrating informal recyclers through micro-entrepreneurship opportunities. In the city of Warangal, city officials created a model where small, informal recyclers who primarily depend on recycling for their livelihoods were incentivized to collect and trade waste. This was achieved through formalized collection centres, where recyclable materials like paper, plastic and cardboard were traded on a daily basis. Banyan Nation's data intelligence platform reported the recycling statistics giving city officials a measure of metrics such as landfill diversion and revenue generated for the integrated informal recyclers through formal linkages.

Furthermore, there is an increasing trend of building plastic roads in Indian cities – finely shredded plastic waste is added to heated bitumen, reducing the quantity of bitumen required by 10%. In 2015 the Indian government made the use of plastic waste mandatory in most highways. Innovations in plastic waste valorization are not far off. The start-up Ventana and waste management company Ramky Group are setting up a plant in Hyderabad using patented contiflow cracker technology to extract blendstock – used for making industrial diesel – from waste plastic at low costs: one tonne of waste can yield up to 850 litres of petroleum fuel.

Source: Banyan Nation contribution to World Economic Forum Study, (Pradhan, 2018), (Patelkhana, 2018), (Chandran, 2017)

Circular procurement

Through their decisions on purchasing works, goods or services, city authorities can contribute to the circular economy – closing energy and material loops within supply chains, and minimizing negative environmental impacts and waste creation across the life cycle (ICLEI, 2017). Sustainable Development Goal 12, "Responsible Consumption and Production", sets a target on sustainable public procurement practices.

Circular procurement models		
System level	Supplier level	Product level
– Product service system – Public-private partnership – Cooperation with other organizations on sharing and reuse – Rent/lease – Supplier take-back systems, including reuse, recycling, refurbishment and remanufacturing	– Supplier take-back system – Design to disassembly – Reparability of standard products – External reuse/sale of products – Internal reuse of products	– Materials in the product can be identified – Products can be disassembled after use – Recyclable materials – Resource efficiency and total cost of ownership – Recycled materials

Source: (Jones, et al., 2017)

Circular procurement can be implemented at three levels. The system level addresses contractual methods that the purchasing organization can use to ensure circularity. At the supplier level, suppliers can build circularity into their systems and processes to ensure the products and services they offer meet circular procurement criteria; finally, the product level focuses on the products that suppliers to public authorities may themselves procure further down the supply chain. Both supplier systems and product technical specifications need to be considered when opting for circular procurement.

Circular procurement contracts fall into three general categories:

1. **Product service agreements –** where users pay-per-use or pay for certain levels of performance without owning the product.
2. **Buy-back agreements –** where users purchase the product and the supplier buys it back later, ensuring optimum value retention via reuse.
3. **Resale agreements –** where users purchase the product and sell it to a third party who recovers the item after use, normally for lower-value material reuse or recycling (ICLEI, 2017).

Cities' circular procurement policies usually include:

– Identifying priority sectors, services and products and potential actions (reduce, reuse, recycle, recover, etc.)
– Methods for integrating a circular approach into existing practices
– Criteria for carrying out life-cycle impact assessment of environmental impact
– Defining targets and time frames for the sectors and those responsible for implementation
– Supporting activities such as training, communication outreach and monitoring mechanisms that are required to ensure efficacy

Cities can design tender specifications using a "technical" or a "functional" approach, based on the circular outcome expected. A technical approach addresses measurable requirements against which proposals are evaluated. A functional approach, which could be output- or performance-based, attends to desired results and outputs such as quality, quantity and reliability. Tenders can also have suppliers establish the projected service life of a product and the maintenance and repair services that would be provided with it, and encourage them to keep products and materials in the supply chain after use (ICLEI, 2017).

One example or prioritizing circular concepts in procurement comes from the municipality of Apeldoorn in the Netherlands, which for its €8 million renewal of infrastructure and public spaces asked contractors to demonstrate their skills and knowledge to innovate using circular principles. The partner was then selected based on creativity, instead of their ability to perform at the lowest cost, under an agreement that contains a significant degree of flexibility on specifications.[10]

Industrial symbiosis is another type of circular procurement, focused on a model where one organization or sector uses byproducts from another, including energy, water, logistics and materials. Examples include using food waste to feed farm animals or non-toxic industrial waste to produce energy through incineration. Industrial processes often generate diverse sets of byproducts that can be of use to a variety of sectors. A structured industrial symbiosis programme brokers companies to collaborate on finding ways to use resources, and minimize waste, increase revenue and reduce associated costs (Europa, 2014).

Case study: Industrial symbiosis in Kalundborg, the UK, Western Cape and Wuhan

Kalundborg, Denmark, has been a pioneer in industrial symbiosis since 1961 and now has more than 30 exchanges of water, energy and other byproducts with eight private-sector partners. The UK's National Industrial Symbiosis Program (NISP) engaged more than 15,000 mostly small or medium-sized companies between 2003 and 2013, achieving cost reductions of £1.1 billion and diverting 45 million tonnes of material from landfill. The NISP model created a blueprint for replication around the world, and in 2013 the Western Cape Industrial Symbiosis Program (WISP) was established by the sub-national Western Cape Government, The programme is delivered by GreenCape, a non-profit organization that works to develop the green economy in South Africa. WISP is currently funded by the city of Cape Townand has over 500 member partners, of which one in three has engaged in resource exchange. As city governments are focused primarily on household waste, GreenCape complements the city's efforts in minimizing commercial and industrial waste to landfills.

To help prepare businesses, opportunity workshops are organized to facilitate thinking about tapping unused resources on site, educating them on industrial symbiosis, resource efficiency, and creating matches for resource exchange. GreenCape also introduces businesses to service and technology providers, regulators, environmental consultants, and waste transporters to enable these changes. By making waste diversion a priority for business, the programme has generated ZAR 25.3 million (South African rand) in additional revenue, cost savings of ZAR 18.7 million and private investments of almost a million rand to date. WISP has been able to divert 27,800 tonnes of waste from landfills (about 82,300 tonnes of CO_2 equivalent in greenhouse gas emissions). The city is working on changing the attitudes of business, scaling technological innovation on circular solutions, increasing awareness of real opportunities in the circular economy and getting companies to invest in processing and packaging materials for reuse. The concept is now also being explored in the city of Wuhan, the largest city in central China, where applications include reusing 25,000 tonnes of asphalt road planings for road resurfacing.

Source: (Ellen MacArthur Foundation, n.d.(b)), Inputs from GreenCape and (Humphreys, et al., 2017)

Barriers to embracing the circular economy in cities

Awareness and cooperation among key actors – businesses, consumers, NGOs and government – are needed for cities to make the circular future a reality through systematic distribution, communication and the promotion of circular practices. There are four main types of barriers: financial, institutional, social and technical.

Financial barriers

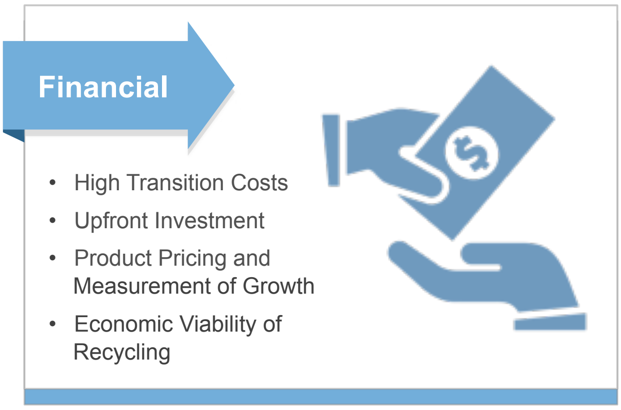
1. **High transition costs:** Transitioning to a circular economy incurs costs to businesses in terms of management, planning, research and development, physical and digital infrastructure. While government can provide incentives or subsidies, these costs nonetheless bring uncertainty and risk.
2. **Upfront investment:** Circular business models require upfront investments that yield returns only over a longer time frame, which can make it difficult to find investors.
3. **Product pricing and measurement of growth:** When indices such as GDP and profit and loss statements do not account for the social and environmental costs of production processes, the benefits of moving towards circularity are understated.
4. **Economic viability of recycling:** Europe, the US and Australia have been exporting recyclable waste to China on ships that brought consumer goods and would otherwise return empty. Now that China has banned some waste imports, it is a challenge to find other economically viable solutions (*The Japan Times*, 2018).

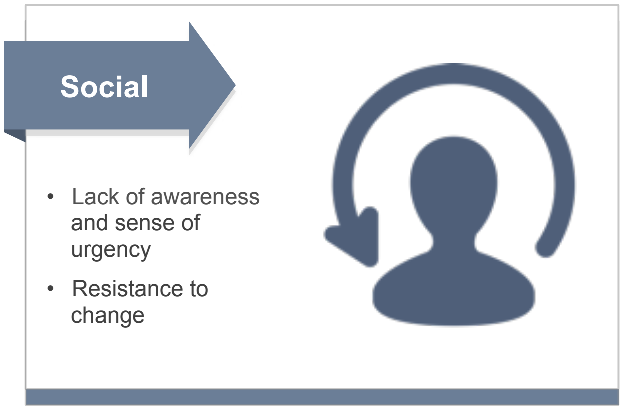
Institutional barriers

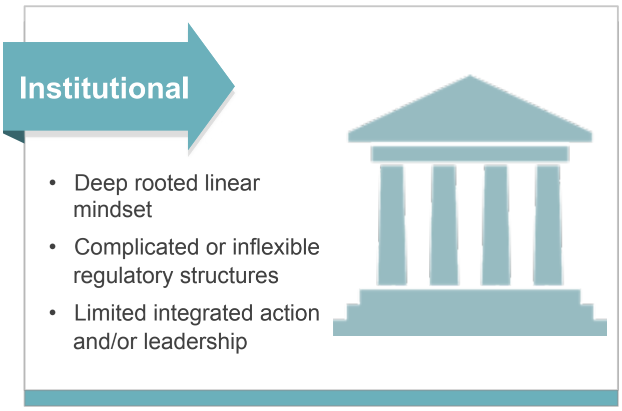
1. **The linear mindset has deep roots:** It will require considerable effort from all actors to move away from established business models and production processes that are designed for a linear value chain and dependence on fossil fuels.
2. **Complicated or inflexible regulatory structures:** Policies, rules and regulations were likewise designed with linear processes in mind and may restrict innovation in circularity. In the Netherlands, for example, competition policy, high taxation on labour and the non-classification of waste as a resource can all hold back the potential for innovative models and partnerships.
3. **Limited integrated action and/or leadership:** Even if cities have dedicated teams working on circular economy initiatives, there is usually no clear distribution of responsibility to city departments. Strong, bold and focused leadership is required.

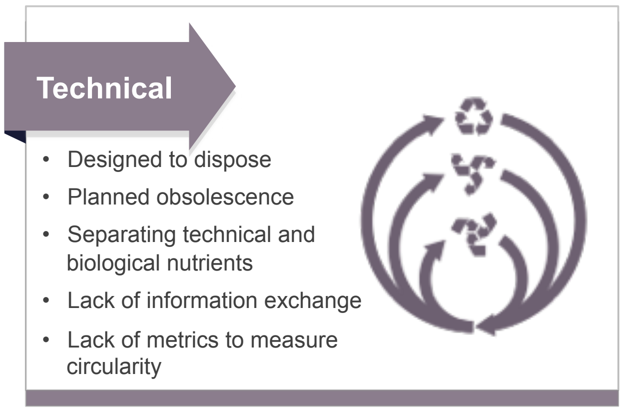
Social barriers

1. **Lack of awareness and sense of urgency:** For consumers, buying new products can be seen as demonstrating higher status than renting, repairing or buying second-hand. For businesses, limited knowledge about the circular economy leads to inertia and aversion to taking risks that disrupt current processes. And while nearly all city governments recycle municipal waste, it can be challenging to focus more on upcycling and reuse.
2. **Resistance to change:** Powerful stakeholders have vested interests in keeping production processes linear, such as waste incineration businesses. Systemic change needs to be gradual to allow such businesses to recoup their investments.









Technical barriers

1. **Designed to dispose:** Producers have little incentive to overhaul their design processes for easier end-of-life material recovery when their products are sold to consumers. Product-as-a-service models, in which the producer retains ownership, provide greater incentives for developing high-quality products that are robust and maintainable.
2. **Planned obsolescence:** Many products are designed to degrade, and limited availability of spare parts effectively forces consumers to dispose of them. In 2015, France defined a law requiring manufacturers to design products that are easier to fix, to label them with information on the availability of spare parts and to offer free repair or replacement for the first two years after purchase.
3. **Separating technical and biological nutrients:** Waste segregation practices and infrastructure at the city level have limited the focus on separating biological nutrients (e.g. food, wood) from technical nutrients (e.g. plastics, metals), though handling them differently is necessary to eliminate toxicity before materials are brought back into the value chain.
4. **Lack of information exchange:** Without platforms to facilitate the exchange of information on material streams, it is difficult for different actors to collaborate. Country-level initiatives such as the UK's Environmental Sustainability Knowledge Transfer Network, the Green Suppliers Network in the US, and Japan's Green Purchasing Network are examples of information-exchange platforms.
5. **Lack of metrics to measure circularity:** It is easier to make progress when progress can be measured, and cities lack standardized methodologies and metrics by which independent institutions can evaluate levels of circularity.

Making the circular economy a reality for cities

Each city stakeholder has a role to play in creating an enabling environment to mainstream the circular economy: governments provide legislative incentives; companies implement new business models; civil society conducts advocacy and research; and individuals change consumption behaviour. This section identifies potential barriers and solutions.

Role of individuals

As citizens, individuals need to engage with city governments on policies and regulations. As consumers, individuals are slowly aligning towards models of access over ownership and must focus more on the functionality and performance of a product, while being more aware about the repair and maintenance costs associated with purchasing. Many are already conscious of the need to reduce (e.g. avoid plastic bags), reuse (e.g. second-hand goods) and recycle (e.g. take-back programmes). The other Rs – recover, repurpose, remanufacture, refurbish, repair, rethink, refuse – are less well known. Before a product is recycled, avenues for reuse, refurbishing, repair or remanufacturing should be explored.

Case study: ReTuna – Eskilstuna, Sweden

The municipality of Eskiltuna has developed a shopping mall, ReTuna, for reused and repaired products. The mall, created as part of the local municipal recycling centre, allows residents to drop off various used items, which are then sorted and upcycled through being repaired or refurbished, and ultimately resold. Different shops for different items (furniture, kitchen equipment, toys, sports equipment, textiles, etc.) are each owned and run by an independent entrepreneur, with support from the municipality. The mall employed 47 people in 2016, and provides opportunities particularly for those with employment barriers.

Source: (Lindner, et al., 2017)

Role of the private sector

Investors can accelerate circular thinking through avenues in municipal bond markets and fairly new structures such as Environmental, Social and Governance (ESG) investing and impact investing[11], which not only minimize emissions and improve resource efficiencies but also overhaul the design process to promote extended life cycles, sharing, reuse and high rates of material recovery. Prominent players include Circularity Capital (a UK-based private equity firm with London Waste and Recycling Board as one of its investors), PGGM (a private pension fund service provider in the Netherlands), Closed Loop Fund (a New York-based private impact investing fund), ING (a Dutch multinational banking and financial services corporation) and European Investment Bank (the European Union's nonprofit long-term lending institution).

Case study: Circular Design Guide – IDEO

Consulting firm IDEO and the Ellen MacArthur Foundation have created a "Circular Design Guide" that helps businesses move from ideas to action in designing for the circular economy. Aimed at "innovators, entrepreneurs and corporate change-makers" who want to better understand and implement circular innovations within everyday operations and identify areas in which they can make their products and services more regenerative, it features 24 steps in four categories – understand, define, make and release – including video interviews, worksheets, case studies and links to technical tools.

Source: (Morris, 2018)

Producers need to make their customers aware of information that enables them to repair products or the options for recycling them. By working with other actors such as city authorities, they can develop programmes to recover their products, which provide more incentives to design products that can be reused or easily recycled. Models include deposit-refund systems (DRSs), in which a fee on the purchase of selected products is reimbursed when the container (e.g. plastic/glass bottles, aluminium cans) is returned.

The private sector can also collaborate with city government to facilitate waste segregation. Indeed, collaboration is crucial to optimizing the system: within an organization (through integrated sustainable product development); between organizations (to achieve industrial symbiosis); between organizations and governments at all levels (for public-private collaboration on recovering waste); and between organizations and end users (bringing used goods back into the value chain).

Case study: ReCirc Singapore and Centre of Excellence on Resource Recovery for Circular Economy

Singapore and the Netherlands are collaborating to exchange knowledge and explore new solutions in areas such as using bottom ash and fly ash in building materials and recovering resources from sludge, food waste and e-waste. ReCirc Singapore, a coalition of business, government, civil society and knowledge institutions, will create a Centre of Excellence on Resource Recovery for Circular Economy to facilitate collaboration, engage citizens and conduct R&D policy. Selected concepts will be researched and tested in "living labs" in both countries, with the companies involved taking proven concepts to market.

Source: (Seegers, 2017) and (Van Boxtel & Nijstad, 2017)

Role of local government

While the number of governments interested in the circular economy is growing, most still lack a sense of urgency. Cities should set up mechanisms to monitor resource usage and performance efficiencies, and use them to set targets and define an evidence-based city roadmap that accounts for local context. For example, Amsterdam identified construction and organic waste as having the greatest potential for added value and job creation: by identifying opportunities to reuse materials, it is reducing CO2 production by 500,000 tonnes per year (Choho, 2017).

Case study: Circular economy route map – London

The London Waste and Recycling Board (LWARB) in 2017 published a route map to accelerate the circular economy in London. In each of five focus areas – built environment, food, textiles, electricals and plastics – it details opportunities, challenges, current initiatives and practical actions. It estimates that moving to a circular economy in these areas could bring London net benefits of at least £7 billion every year by 2036 and 12,000 new jobs by 2030. LWARB is currently developing circular economy metrics and indicators for the city to gather baseline information that will enable target-setting for the future. LWARB is also running a three-year Advance London, circular economy business support scheme. The project offers bespoke support for existing circular economy SMEs to scale-up, and more traditional SMEs to transition, allowing them to explore a more circular model.

Source: Contribution of London for the World Economic Forum study

City governments looking to decouple economic growth from natural resource use and environmental impacts can pursue absolute or relative strategies. Absolute decoupling, more suited to developed countries, focuses on waste prevention, high-value resource recovery, circular resource flows and adjusting social norms. Relative decoupling, more suited to developing countries, focuses on improving resource efficiencies while net consumption continues to rise until a socially acceptable quality of life has been attained. Each strategy requires a combination of resource productivity improvements, increased use of clean energy and waste reuse (IRP, 2017).

Enabling the environment for the circular economy

Cities can facilitate circular initiatives by piloting and scaling novel models in their own operations. To finance these, they can explore financial instruments such as the municipal bond market and the emerging field of green bonds. In 2014, Goldman Sachs ran a $350 million green bond offering for the Washington DC Water and Sewer Authority to help fund new infrastructure: the bond's 100-year maturity matches the life of the asset (Burckart & Butterworth, 2017). While there are currently no green bonds dedicated to the circular economy, city governments could work to establish such a market.

Cities can provide incentives to businesses, through subsidies or tax breaks, to adopt circular practices. They should also remove subsidies that encourage the use of resources or consumption of non-renewable energy, and consider tariffs to incorporate externalities in pricing mechanisms. Cremona, Italy, is testing the introduction of a tariff on waste that cannot be recycled: residents are given orange 60-litre rubbish bags; with each additional bag they use, their rubbish collection fee increases (D'Antonio, 2017). Cremona is also coordinating UrbanWINS – a large European project on waste-management strategies. Launched in 2016, the three-year project is analysing strategies in 24 European cities with the objective of highlighting the most innovative. Together with partners including universities, companies and NGOs, it is studying how materials flow through cities to get a better understanding of what is produced, consumed and discarded and help cities to define more holistic strategic plans to prevent and manage waste.

Case study: Improving mass transit use by sorting refuse – Curitiba, Brazil

As the city of Curitiba grew, refuse piled up in narrow alleyways where trucks could not retrieve it. The city developed a programme instructing children on how to separate it out; the children, in turn, taught their families. In return for sorted through the rubbish, people were paid in fresh food or bus tokens, which increased use of the mass transit system. Today, 85% of Curitiba citizens use the bus, and 90% participate in recycling. The city recycles 70% of its refuse – one of the highest rates in the world.

Source: (McDonough, 2017)

Cities should consider the circular economy in their urban planning. In a simulated model of energy use across the residential, commercial and industrial sectors of 637 cities in China, resource-efficient urban planning – including urban-industrial symbiosis strategies, such as reusing industrial heat waste in urban district energy systems – was shown to reduce greenhouse gas emissions by 15% to 36% (IRP, 2017).

Regulate to scale circularity

Cities have an important role as regulators. They need to engage citizens and the private sector to ensure their voices are heard when framing policies and regulations: they should not burden the private sector, but should instead encourage the easy movement of materials and ensure mechanisms are in place for testing, repairing and maintaining goods throughout the product life cycle. In Vancouver, the Green Demolition Bylaw requires homes created before 1940 to be deconstructed instead of being demolished, with a minimum of 75% of materials reused or recycled. Cities can leverage Extended Producer Responsibility (EPR) to encourage producers to innovate: measures include defining criteria for the type and amount of materials used to manufacture or package products, benchmarks for reducing waste and pollution, or information disclosure systems.

As already noted, procurement can strategically promote circular economy practices. In the Netherlands, Utrecht has committed to increasing its share of circular procurement from 4% of annual expenditure to 10% by 2020. For example, the city challenged contractors to provide circular solutions for developing a cycle route: the winning solution used 100% recycled asphalt on the lower layer of its road (Choho, 2017).

Case study: Scaling the circular economy in China

China's 2009 Circular Economy Promotion Law required central government and local authorities to include circular economy practices in their socioeconomic development plans. In 2017, an evaluation showed that resource productivity increased by more than 20% between 2011 and 2015, and ten major pilot projects were completed successfully. In May 2017, the Chinese government issued "The Guiding Action Plan for Circular Economy for 2016–2020", which includes new actions to promote circular development.

Source: (IRP, 2017)

Leading the transition through collaboration

Material flows in the circular economy can be complex, requiring collaboration across different sectors to take advantage of possible synergies. Cities can play a pivotal role in leading collaboration and stimulating action. For example, the Circular Peterborough Commitment (UK) brings organizations together to develop pilot initiatives that encourage a more sustainable approach to business in the city (Environment Capital, 2017).

Case study: Innovation platform for circular economy – Paris

The economic development and innovation agency Paris&Co boosts the city's innovation ecosystem by incubating new companies, beta-testing innovative solutions, and organizing events to help start-ups network with corporate partners. In 2017, it developed a dedicated innovation platform on the circular economy, aimed at stimulating collaborations in the areas of sustainable supply, ecodesign, territorial ecology, functional economy, responsible consumption, extending the life of goods and waste management.

Source: Paris&Co website

Case study: Resource Innovation Solutions Network (RISN) – City of Phoenix

Launched in 2014 by the City of Phoenix and Arizona State University, the Resource Innovation and Solutions Network (RISN) facilitates collaboration by providing knowledge and tools and building the capacity of stakeholders to use best practices. It has, for example, worked to evaluate the viability of a region-wide organics management system and cross-departmental collaboration on circular economy initiatives in municipal operations. In 2017, the RISN Incubator began providing business development and acceleration services to early-stage technology solutions ventures focusing on waste diversion and improvements in processing or the use of waste as a raw material for new products or energy.[12]

Source: City of Phoenix contribution to World Economic Forum Study

Cross-city collaboration to develop value chain-based partnerships and share innovative solutions is also important. For example, FORCE, a project sponsored by the European Commission, involves four cities (Copenhagen, Hamburg, Lisbon and Genoa) in partnerships on four materials: plastic waste, strategic metals from electronic and electric equipment, surplus food and biowaste, and wood waste (FORCE, 2017).

Role of civil society

Several civil society institutions educate and advocate on transitioning towards a circular economy, working with individuals, communities, the private sector and governments to facilitate collaboration, support and innovative solutions, and provide recommendations on policies and regulations. NGOs, international organizations, think tanks, not-for-profits, social enterprises and academia all have a role in making the transition possible.

Case study: The Ellen MacArthur Foundation

The Ellen MacArthur Foundation was established in 2010 with the aim of accelerating the transition to a circular economy. Since its creation the charity has emerged as a global thought leader, establishing circular economy on the agenda of decision-makers across business, government and academia. The Foundation's work focuses on five interlinking areas: Education (inspiring students to rethink the future through the circular economy framework), business and government (catalysing circular innovation and creating the conditions for it to reach scale), insight and analysis (providing robust evidence about the benefits and implications of the transition), systemic initiatives (transforming key material flows to scale the circular economy globally), and communications (engaging a global audience around the circular economy). It is currently conducting in-depth research on the circular economy in cities.

Source: Ellen MacArthur Foundation to World Economic Forum Study

Case study: Circle Economy

Circle Economy, a not for profit organisation started in 2011, has developed the City Circle Scan approach to assess opportunities for circular projects in a city. It starts by assessing the economic strength and political will in different sectors, and analysing the city's current flows of resources, materials, energy, and labour. It then outlines strategies and proposes an action agenda for the short and long term. The approach has so far been applied in Glasgow, Amsterdam, Brussels and Bilbao.

Source: Based on inputs provided by the Circle Economy

Conclusion

Cities need to prioritize a systematic transition from the linear paradigm of production and consumption to a circular model, keeping materials in use for as long as possible and maximizing their economic value. As this report has shown, innovations have already begun in cities across the world in sectors including the built environment, energy, healthcare and waste management.

The transition cannot be achieved by any single actor. It will require collaborative efforts across the value chain, involving individuals, the private sector, different levels of government and civil society. Companies need to design products with circularity in mind, and build components that can close loops in production. Individuals have a key role in creating demand. The public sector needs to play its part in making available the necessary infrastructure, and formulating policies and regulations that incentivize innovation without imposing burdens that dampen growth.

City governments are especially well placed to take the lead. Given that they are primarily responsible for waste management at the local level, they have a unique opportunity to map resources and collaborate with businesses and residents in closing nutrient loops (both technical and biological) through urban-industrial symbiosis or knowledge exchange programs. By working to accelerate the transition to the circular economy, cities will enhance sustainability and minimize the economic, social and environmental impacts of the current ways in which we extract, consume and dispose of resources.

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Endnotes

1 Cradle to Cradle introduced the concept of biological and technical nutrients and provides a coherent framework for restorative and regenerative systems. Within Cradle to Cradle is the concept of what has now become known as the Circular Economy as well as the introduction of many of many other qualities – healthy and safe materials, material reutilization, clean energy, clean water and social fairness. The 2002 book was titled Cradle to Cradle: Remaking the Way We Make Things and when published in China in 2005, was translated by Tsinghua University and published by Tongi University under the title Cradle to Cradle: The Design of the Circular Economy. For more information on Cradle to Cradle please visit https://en.wikipedia.org/wiki/Cradle-to-cradle_design

2 International Resource Panel (IRP), 2018

3 An assessment that accounts for planetary limits (biophysical, economic and societal). Absolute sustainability assessment (ASA) gives a glance at a company's level of circularity stewardship, so investors can relate it to fiscal risk (CIRAIG, 2015).

4 Eco-efficiency aims to minimize the "volume, velocity and toxicity" of the linear "take-make-dispose" materials flow and is not focused on making flows completely "circular". Recycling usually results in downgrading (downcycling) of the material. Eco-effectiveness is a mechanism that recouples environmental and economic systems through "metabolisms" that enable materials to maintain and even augment their inherent characteristics through upcycling (CIRAIG, 2015).

5 For more information on how cities are using collaborative practices and exploiting the potential of the sharing economy, the World Economic Forum recently published a whitepaper "Collaboration in Cities: From Sharing to 'Sharing Economy'", which can be accessed here.

6 Activity alignment of at least two organizations in the supply chain process in coordinating the supply of goods and services, creating competitive advantage through improved service or efficiency improvements (IGI Global, s.d.).

7 Water withdrawals are defined as freshwater taken from ground or surface water sources, either permanently or temporarily, and conveyed to a place of use (OECD, 2015).

8 Bioswales are landscape elements designed to concentrate or remove silt and pollution out of surface runoff water. For more information, see https://en.wikipedia.org/wiki/Bioswale.

9 Source: interviews with Cisco for the World Economic Forum study.

10 (Lindner, et al., 2017) and (Mineralz, 2017).

11 ESG investing incorporates all financially relevant (i.e. material) environmental, social and governance considerations into investment decisions. It aims to be thoughtful about how sustainability-related risks and opportunities are factored in by investors. Impact investing has a double bottom line where the desire for attractive financial return coexists with an intention to produce a positive impact on the environment or society. Although these two concepts have some overlap, they are fundamentally distinct (Burckart & Butterworth, 2017).

12 For more information on the partnership between the City of Phoenix and Arizona State University, contact Brandie I. Barrett at brandie.barrett@phoenix.gov and/or Bill Campbell at williamfcampbell@asu.edu.

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