CHARLOTTE

ENVISION CHARLOTTE

METABOLIC

CIRCULAR CHARLOTTE

Towards a zero waste and inclusive city

SEPTEMBER 2018

EXECUTIVE SUMMARY

Charlotte is the first city in the United States to make a commitment to adopting the circular economy as a public sector strategy. In its circular future, all of the material resources that now end up in landfills will be the basis for Charlotte's next industrial revolution: the foundation for an era of green manufacturing that unlocks new technological advances, increases local resilience, and supports workforce development.

Our report, "Circular Charlotte: towards a zero waste and inclusive city," explores how Charlotte can start implementing a strategy to become the first circular city in the United States. We investigate how many valuable resources are currently lost through Charlotte's waste system, and how these could be diverted into new, high-value uses. We present a vision, co-created with stakeholders from the city, for how a Circular Charlotte could look and function. Finally, we describe a roadmap of actions that should be taken on the pathway towards this vision, and detail five initial business cases that can serve as a starting point for action.

Growth brings transition opportunities

Charlotte is in the midst of a building boom. This expansion of the city points to Charlotte's increasing popularity as a place to live and work: it is now ranked as one of the fastest-growing metropolitan regions in the United States (Thomas, 2018) and was recently named the number one city for attracting millennials (Abadi, 2017). Beyond changing physically, Charlotte is undergoing a broader transformation in its character, evolving from a banking-focused city with a history of manufacturing and logistics, to a dynamic urban center with unique specialties in high-tech industry. This growth is not only an opportunity to cash in on Charlotte's successes, but also to address challenges, such as economic mobility, on which Charlotte is currently ranked lowest out of America's 50 largest metro areas (Chetty, 2017).

The circular economy – a new economic system that is regenerative and waste-free by design – can not only eliminate negative environmental impacts and create new sources of value, but also be used to bridge the wealth divide and create new pathways for upward mobility in Charlotte. Within a circular economy, products and materials are circulated at high value for as long as possible, extending the life of products and enabling high-value component and material recovery for reuse or recycling. The systemic transformation required for a circular economy – from the development of new technologies, to the evolution of new forms of collaboration and business models – has also been shown to have great potential in generating new employment and creating opportunities for skills development.

THE CIRCULAR ECONOMY

The vast majority of our economic system can currently be defined as linear. We extract resources, which are then transformed to products via the use of labor, energy, and money, and then, soon after their use, these products are thrown away. Every time a product that we have crafted and manufactured with care ends up in landfill, not only do we lose the physical resources it is made up of, but also all of the time and energy that went into its creation. McKinsey estimated that up to 630 billion dollars a year is lost in Europe alone through the loss of materials in the linear economy (EMF & McKinsey, 2011).

In parallel, these material losses translate to unrealized employment potential. The U.S. EPA and the Institute for Local Self Reliance estimate that low-value activities that result in material losses (like incineration and landfilling), only generate 1–6 jobs per 10,000 tons of goods disposed of. Recycling generates an estimated 36 jobs for the same amount of material, while reuse and refurbishment are by far the biggest winners, creating almost 300 jobs for each 10,000 tons of "waste."

To move towards a circular economy, where the value-generating life-cycles of products are extended to the maximum extent possible, we should:

- Design all products for easy repair, disassembly, and full recyclability.
- Create the necessary business structures and incentives to get these materials back into the economy at their highest possible value (preferably as whole products or components).
- Strive to use only responsibly-sourced renewable resources for both energy and material provision.
- Avoid the use of toxic substances that may continue to circulate in our environment.

Successfully achieving this transition is not simply about product reuse and recycling: it means a systems change that requires a new mindset. Preserving the complexity and value of our products should be structurally incentivized, and negative impacts on people and the environment should be eliminated by design. This transition can be supported through alternative business models and purchasing patterns that will support the recovery of materials, such as leasing models and advanced approaches to extended producer responsibility (systems that make manufacturers responsible for what they create and sell, even after the products are sold). Perhaps most importantly, achieving this transition will require a shared vision and strong leadership from both government and civil society.

VISION OF A CIRCULAR CHARLOTTE

If we take these high level ideas about the circular economy and actually apply them to Charlotte, what kind of changes would potentially take place? Here we envision, from a 2050 perspective, how Charlotte might look if it achieves the full spectrum of a circular economy. We have organized the vision around four thematic areas. For each of these four areas of performance, we have also developed Key Performance Indicators (KPIs) to monitor Charlotte's progress (see page 30).

CHARLOTTE AS A ZERO WASTE CITY

In 2050, Charlotte might proudly call itself a Zero Waste City, where 98% of all residual materials are separately collected. Every household could be equipped with smart sorting containers with built-in technologies to tell users if they've sorted something incorrectly. Residents would get reward points paid directly into their digital wallets for every pound of correctly sorted waste. They could use their earnings for the purchase of local goods branded with the Circular Charlotte label, many of which might have been remanufactured or grown from those same residual streams. If they have reward points left over, they could also use them to pay for their fully-renewable energy bill, or even pay their taxes. A real-time resource monitoring platform, the Charlotte Circularity Dashboard, would continuously reports how much is available of different kinds of residual goods – from citrus peels to old shoes. These resources would be automatically diverted to various processing facilities throughout the city, run by large companies and small entrepreneurs alike. The Dashboard would keep a record of orders placed requesting different materials, and ships off materials to the earliest bidders. Due to Charlotte's strong position as a logistics hub, the city would also accept and process materials from nearby counties, adding to the base of resources used for local manufacturing.

CHARLOTTE AS A RESILIENT AND HEALTHY CITY

As other circular industries develop, Charlotte and its surrounding region could become increasingly independent of foreign imports, with almost all materials sourced from local cycles. Even local food production has the potential to grow immensely, with the advancement of vertical farming technology and the reuse of organic waste streams as fertilizer. Most of Charlotte's schools would also have their own small-scale aquaponics facilities, which would be used both for hands-on science education as well as to provide farm-fresh produce and fish to the schools' cafeterias. Further efforts to increase the city's health and resilience could focus on the decentralization of certain utility services. Renewable energy, decentralized battery storage, and smart distribution of energy through the city's smart grid could make Charlotte's energy system resistant to the impact of storms or floods, with most damage remaining localized.

Though some of these ideas may seem farther off in the future than others, every plan starts with imagining the reality we aim to achieve. The picture we describe here will certainly not be a perfect reflection of what actually transpires, but it can provide a starting narrative and inspiration for the next decades of Charlotte's development.

CHARLOTTE AS AN INNOVATIVE CITY OF THE FUTURE

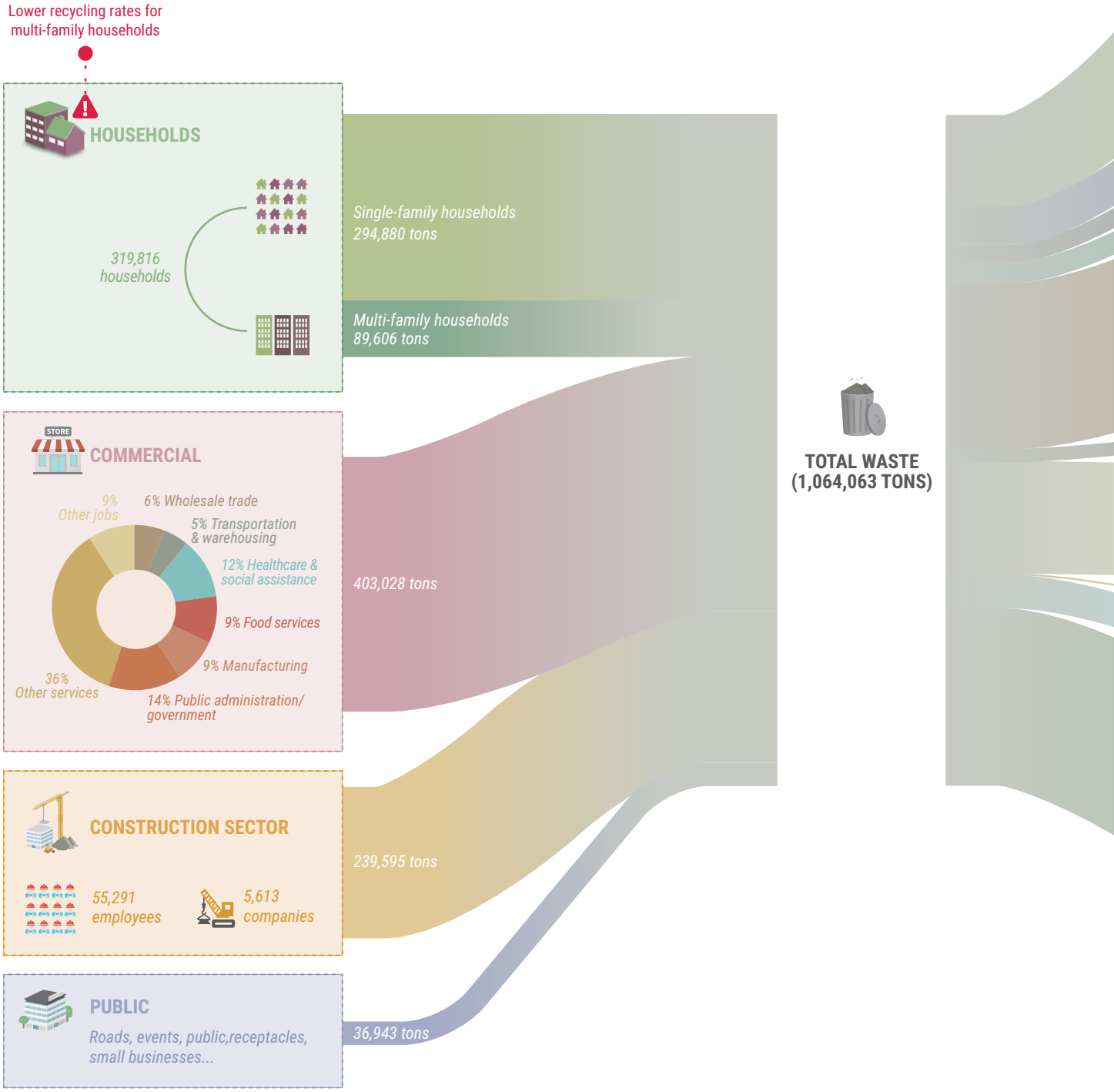
With Charlotte's innovations in waste collection and sorting, which would result in the supply of previously-unavailable high-quality and pure resource streams, a whole new cluster of industries could began to develop throughout the city. New product development would explode in the early 2020s. At first, the major focus of R&D activities would be on processing textiles, plastics, and construction wastes. In 2023, CharM, the city's newly-opened materials lab, a joint project of several of Charlotte's incubators and accelerators, would begin experimenting on how to convert collected organic wastes into new materials – like clothing, furnishings, and biodegradable packaging. The strong need for materials and product innovation because of the city's ambitious circularity goals would also lead University of North Carolina Charlotte to establish a new educational facility, the Charlotte Institute of Circular Design and Engineering (CICDE). The Circular Charlotte brand would help the city consolidate its leading position globally, and cement Charlotte's top position in global rankings such as the Sustainable Cities Index.

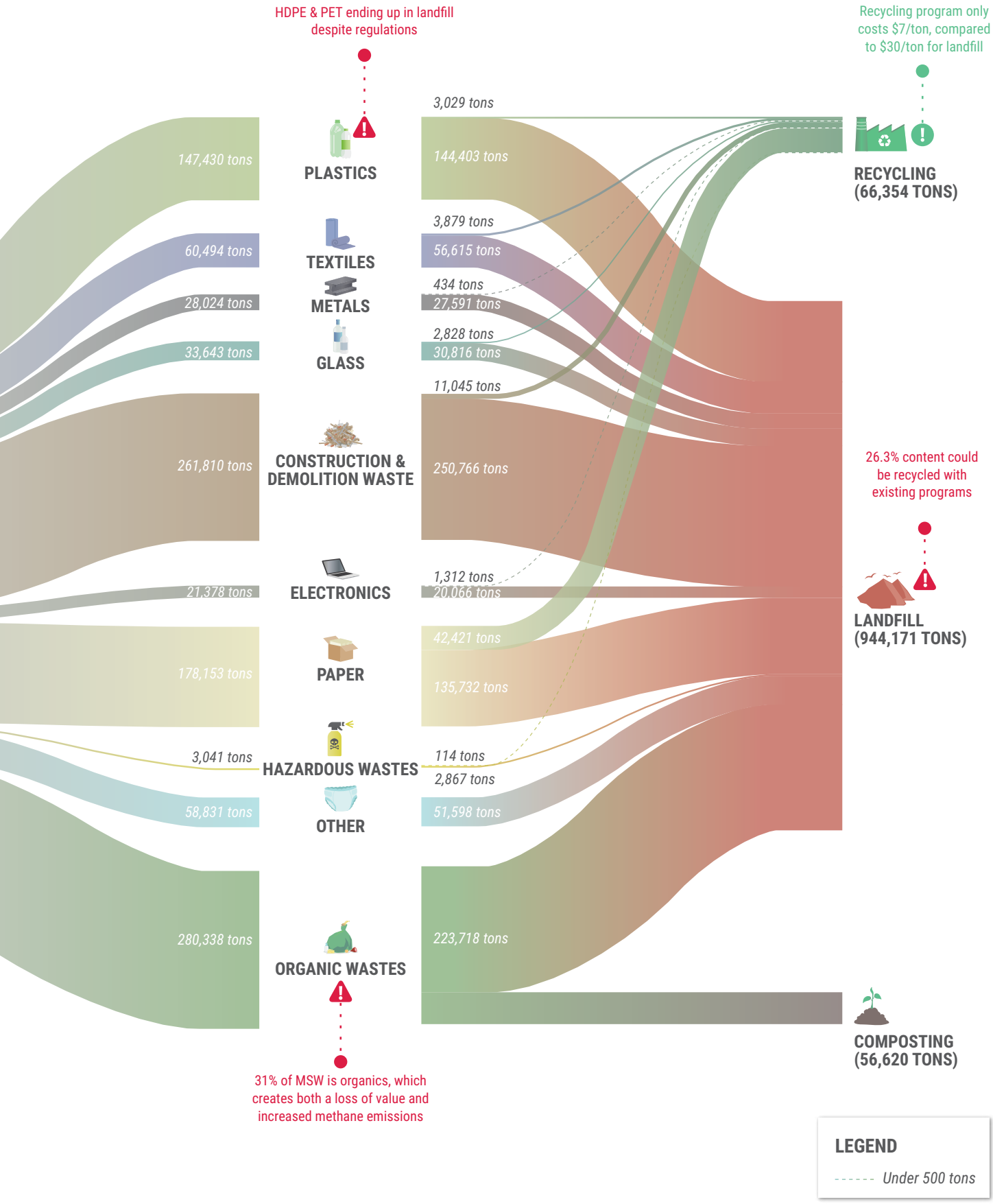
CHARLOTTE AS A CITY WITH OPPORTUNITIES FOR ALL

By 2050, Charlotte could have less than 0.5% of its population living in poverty. Initial efforts on establishing circular industry and innovation would be largely focused on skill development, training, and inclusive programs designed to uplift those who are economically disadvantaged. In 2019, the city's solid waste department could establish a test rehabilitation program for the homeless community, providing employment in plastic waste sorting and remanufacturing. Plastic wastes, which are of too low a quality for automated processing at that time, would be sorted, washed, and shredded for the production of small batches of local products like street furniture, waste bins, and trophies for school sporting events. Some of the trainees involved in the pilot program could go on to start their own companies focused on recycling and product manufacturing.

HOW CIRCULAR IS CHARLOTTE TODAY?

This graphic shows the types of wastes generated in Charlotte and where they ultimately end up. Only 11.5% of the materials that currently enter Charlotte's waste system each year are recycled or composted. In order to make Charlotte circular, the city will need to make it convenient and affordable for households and businesses to recycle and develop products and markets that can accept recycled materials. For example, 16% of the waste that ends up in landfill is food waste, partly because there are no free organic waste recycling programs that provide an alternative to landfill.




HDPE & PET ending up in landfill despite regulations
Recycling program only costs $7/ton, compared to $30/ton for landfill
147,430 tons
PLASTICS
3,029 tons
144,403 tons
60,494 tons
TEXTILES
3,879 tons
56,615 tons
28,024 tons
METALS
434 tons
27,591 tons
33,643 tons
GLASS
2,828 tons
30,816 tons
11,045 tons
261,810 tons
CONSTRUCTION & DEMOLITION WASTE
250,766 tons
21,378 tons
ELECTRONICS
1,312 tons
20,066 tons
178,153 tons
PAPER
42,421 tons
135,732 tons
3,041 tons
HAZARDOUS WASTES
114 tons
2,867 tons
58,831 tons
OTHER
51,598 tons
280,338 tons
ORGANIC WASTES
223,718 tons
RECYCLING (66,354 TONS)
26.3% content could be recycled with existing programs
LANDFILL (944,171 TONS)
COMPOSTING (56,620 TONS)
31% of MSW is organics, which creates both a loss of value and increased methane emissions
LEGEND
Under 500 tons

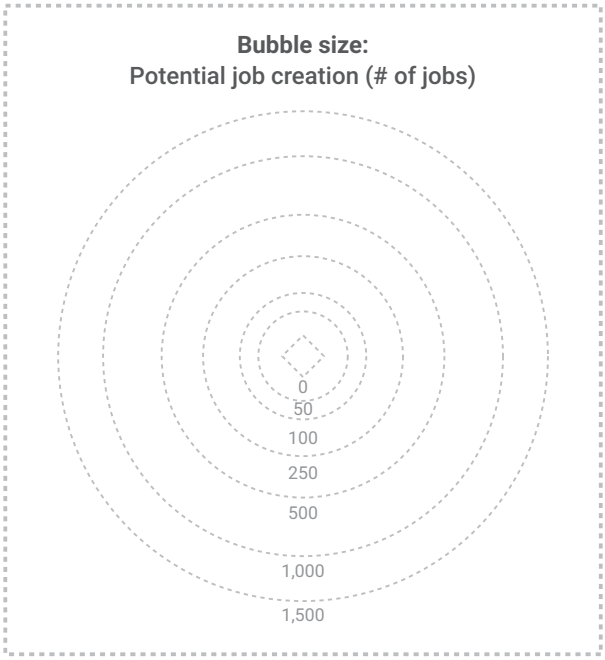
UNCOVERING THE POTENTIAL OF CIRCULARITY

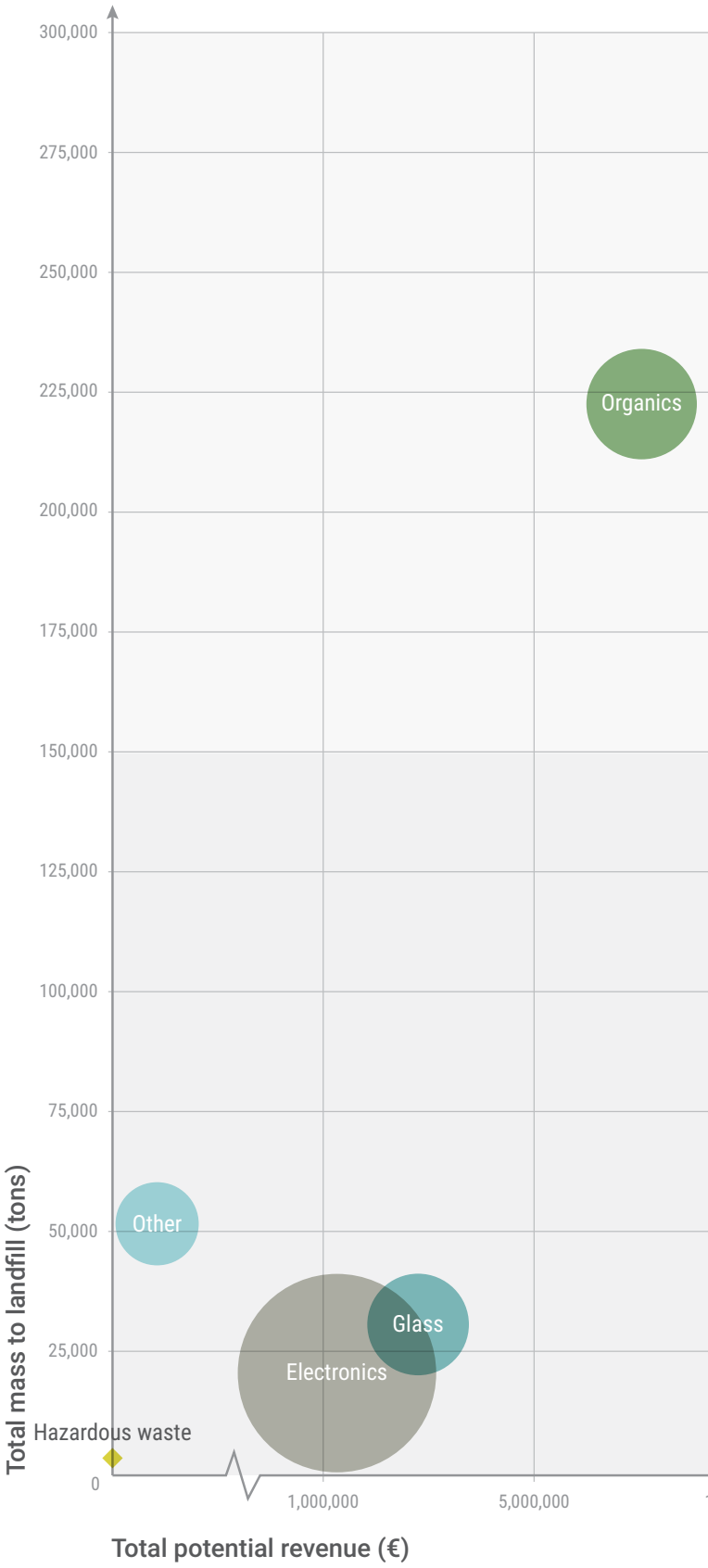
This figure shows the potential mass (y-axis), revenue potential (x-axis), and job creation potential (bubble size) for each of the material categories currently ending up in Charlotte's landfills.

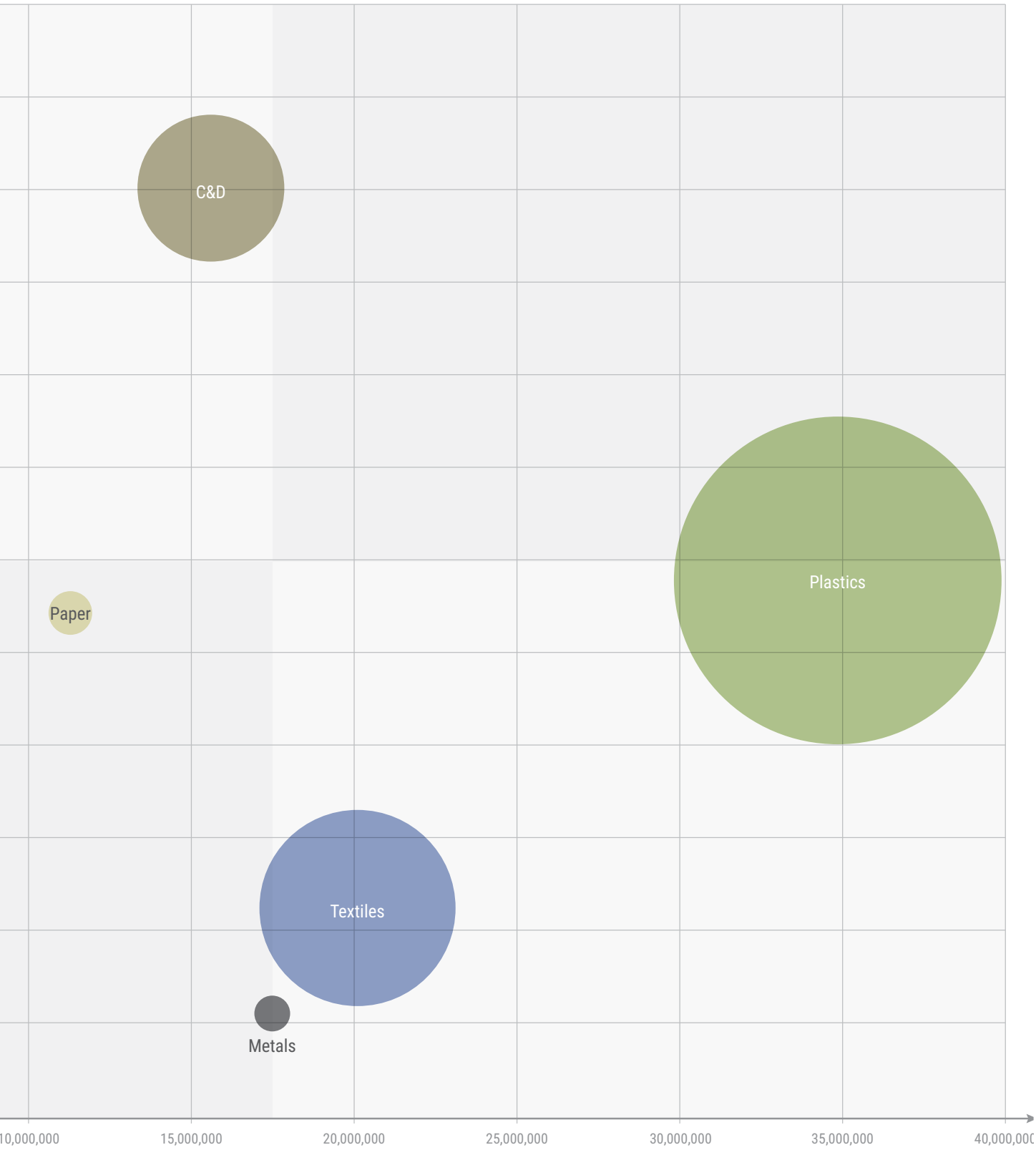
From the graphic, we can see that there is a significant amount of value going literally to waste. In total, we calculate a residual market value of $111 million in material value and a job creation potential of more than 2,000 new jobs that would be created if these materials were recycled.

It is important to note that here we've only considered the residual scrap value of the materials when they are sold for recycling. When circular business strategies are applied (such as refurbishment, repair, or remanufacturing), more value can be retained than what materials are worth on the scrap market. Design for modularity and disassembly can further increase the value that can be recovered from waste materials, though this also requires participation from parties upstream in the value chain.

This analysis shows the value of all the materials once they have been collected, excluding processing and collection costs. The business cases we developed in Chapter 5 of this report show both the costs and revenues of selected material streams when they are processed in a circular manner.






C&D
Plastics
Paper
Textiles
Metals
10,000,000
15,000,000
20,000,000
25,000,000
30,000,000
35,000,000
40,000,000

CIRCULAR OPPORTUNITIES

If done right, a circular economy in Charlotte will create opportunities for local employment, reduce the socio-economic divide in the city, and establish new industries that lead to greater local resilience and economic vitality. Ideally no waste will be going to landfill and all materials flowing through the city will be used as the basis for new circular manufacturing. By definition, training in new skills (such as product repair, remanufacturing, or circular demolition techniques) is required for the transition, creating job potential. In addition to the socioeconomic opportunities that this pathway unlocks, there are a number of other benefits.

Landfilling materials is associated with both financial costs and environmental impacts. Charlotte has recently adopted a low carbon strategy, through which it will strive for a net annual CO_2e emission of less than two tons per person. Reducing the total waste-to-landfill is one way of reducing emissions. Conventional landfilling of municipal solid wastes contributes between 138-601 lbs CO_2e per ton (Manfredi et al., 2009). In total, between 0.08 - 0.34 tons of direct CO_2e emissions per person can be reduced by shifting to a completely zero-waste system.

An additional issue is that sending waste to landfill increases the demand for virgin resources, and can exacerbate impacts upstream associated with material extraction. Recycling materials such as plastic and paper can prevent the need for new production of these materials, while even waste incineration can reduce the need for fossil fuels such as natural gas or coal in electricity production. As an example, you can consider wood and paper production, which has a large land footprint. To produce the wood and paper that is currently landfilled in Charlotte, you would need an area of nearly 17 square miles. To put this in perspective, you can consider that this is around 5.6% the area of Charlotte or more than 100 times the area of Charlotte's Freedom Park. A large share of this land area could be left unexploited if paper and wood were recycled instead of sent to landfill.

Finally, activities of other stakeholders outside of the scope of Charlotte can have a large impact on how the waste system of Charlotte functions and the opportunities that can be achieved with circularity. One example is China's decision to limit the import of recyclables to those of a high quality, due to environmental and health reasons.

Chinese policy on materials accepted and the quality of recyclates will have a large impact on global markets for recyclables and is expected to have a large negative impact on United States recycling businesses and threaten thousands of jobs (Rosengren, 2017). In some cities in the United States, this ban has already resulted in the refusal of certain types of plastics for recycling (van Fleet, 2017).

By adopting a circular economy strategy, Charlotte can insulate itself from these kinds of impacts and provide local solutions for neighboring counties.

If all plastics landfilled in Charlotte were recycled instead, this would save 936,329 barrels of oil per year while creating jobs and revenue

BUSINESS CASES FOR A CIRCULAR CHARLOTTE

Through our analysis, we have shown that the combined residual value of the waste streams currently ending up in Charlotte's landfills amounts to $111 million per year. The top four opportunities of plastic, textiles, construction and demolition waste (C&D), and organics when taken together can reduce landfill mass by nearly 65%, create just under 2,000 jobs, and generate nearly $80 million in revenue.

These amounts do not take into account the cost of collection or processing, nor do they take into account the real added value that can be generated if these materials are not sold as scrap, but instead turned into higher-value products.

To delve deeper into the real costs and potential value generated through resource processing and recovery, we explore five business cases for circular business models that fit the regional context, matched with local interest from stakeholders, or addressed some of the most impactful or problematic waste flows.

These five cases include:

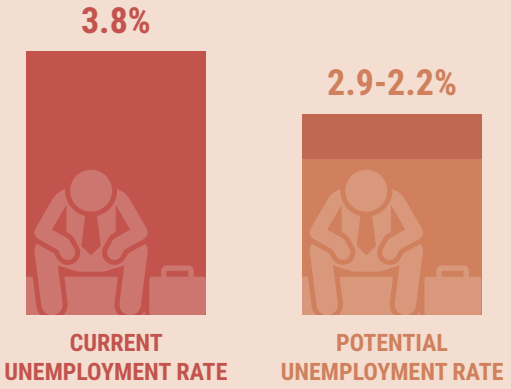
1. Developing a local supply chain manager to organize a closed-loop textiles chain for linens and uniforms used in hotels, hospitals, etc.
2. Scaling up food waste collection and establishing a commercial-scale facility to recycle food waste into larvae for livestock feed.
3. Setting up a Materials Innovation Lab for student entrepreneurs to develop innovations for upcycling specific waste fractions into new products.
4. Setting up a incentivized reverse logistics system to provide households with an incentive to recycle materials at a high quality.
5. Establishing a circular concrete chain in Charlotte and producing new concrete from recycled concrete and post-consumer glass.

While these business cases cover a relatively small share of the wastes that are going to landfill (around 11-15%), they can result in significant benefits in terms of job creation, CO_2e emissions reduction, and most importantly in terms of building local capacity for circular economy innovation. Out of a set of 29 Key Performance Indicators (KPIs) we propose to measure circularity in the city, each business case can improve between 13-19 indicators.

Taken together, we estimate that these business cases can generate between $22 and $34 million in revenue (making more money as they grow over time), and $6.4 million in profit per year once they are established. Since this is based on only 11-15% of the mass of material going to landfill, it can be seen as in line with (or exceeding) the rough estimates of material value from our revenue assessment.

Together, the business cases can divert 103,000-145,000 tons from the landfill, reducing the total mass by 10.9-15.4%.

The business cases can collectively create 290-492 jobs, reducing the number of unemployed by 24-41%.



DEVELOPING A STRATEGY FOR CHARLOTTE

BARRIERS

The magnitude of the transformation that has to happen in Charlotte to achieve the circularity goals outlined in the strategy will require a coordinated set of actions over a number of years, supported by strong leadership from local government, the private sector, and civil society. There are still some significant barriers to tackle along the way (see page 54).

In conversations with stakeholders, we identified a range of barriers - both real and perceived - that need to be addressed through the city's circular economy strategy.

One key barrier is that there are still some gaps in the physical and technological infrastructure that we need for a transition to a circular economy. For instance, Charlotte currently has no means for recycling styrofoam, plastic dinnerware and cutlery, aluminum or plastic foils and wraps, diapers, ceramics, or any glass that is not used in packaging (glassware, plate glass).

Perhaps more importantly, the majority of products on the market are not designed for high-value reuse and recycling. They are often made of mixed materials, have unknown additives, are assembled with glues making them difficult to take apart, or use problematic dyes and colorants that can contaminate whole recycling streams.

On the social and cultural side, one of the most fundamental challenges that all societal transitions face lies in changing the behavior and mindset of people: their willingess to participate in recycling programs and in the development of new, circular business. The transition to a circular economy will require a great deal of new skills and knowledge: a whole new workforce of people trained to remanufacture products and reuse materials in different ways.

The financial part of change management can sometimes be challenging. Currently, most recyclables have low value - in many cases, because of high levels of contamination among the collected resource streams. A bale of pure PET bottles has much higher value than a bale of mixed plastic, for instance. It is essential to work actively with the market to develop solid business cases for circular resource management.

There are, finally, a number of political and legal barriers. One of these is the solid waste interlocal agreement between Charlotte and Mecklenburg County, which currently dictates how all of Charlotte's waste is handled after collection. On the day-to-day level, existing rules and regulations can hamper how certain waste streams are used and where certain activities (for example, food production) can take place.

ACTIONS

Charlotte's transformation to a circular city clearly cannot take place overnight. Near term actions should focus on building awareness among the city's citizens, business owners, and other key stakeholders on what the circular economy is and the different opportunities it can provide as well as laying the groundwork for tackling some of the barriers we identified.

In addition, it is essential to identify tangible actions, showcases, and circular business cases that can be executed quickly in order to build support for the approach and demonstrate its value. Further steps should include capacity building and efforts geared at longer-term transformation, such as neighborhood action plans, the establishment of new partnerships and institutions, and monitoring programs to track the city's progress on circular economy metrics (i.e., the KPIs presented in Chapter 2). A short, mid, and long-term set of activities that Charlotte should undertake are presented in the roadmap in Chapter 4. We have divided near-term actions that the city should take into several categories:

- Establishing public sector commitment and developing a circular economy strategy
- Launching a communications strategy and developing the Innovation Barn as the city's local circular economy showcase and innovation center
- Building Circular Charlotte's international profile
- Creating circular economy programs for the city and securing long-term staffing and financing
- Building circular infrastructure and resources
- Establishing the basis for data collection and performance monitoring

NEXT STEPS

In addition to actions that the city should take in the near term, we have summarized some of the steps that other groups of stakeholders (such as funders, commercial and industrial sectors, NGOs, and knowledge institutes) can take in a coordinated effort towards achieving a circular economy (see Chapter 6).

The initial groundwork for the circular transition, however, should be laid by the government. The city has already demonstrated its public sector commitment to a circular economy. Now this must be communicated to the local community and made tangible. The Innovation Barn can become one of the first meeting places and centers for activity and learning on this topic, kicking off the start of this shared journey.

TABLE OF CONTENTS

01 CIRCULAR TRANSFORMATION IN CHARLOTTE 16

Introduction 17
The city of Charlotte 19
The circular economy 21

02 VISION OF A CIRCULAR CHARLOTTE 24

Developing a circular vision 25
Charlotte as a zero waste city 26
Charlotte as an innovative city of the future 27
Charlotte as a resilient and healthy city 28
Charlotte as a city with opportunities for all 29
Measuring Circularity 30
Charlotte as a zero waste city 31
Charlotte as an innovative city of the future 32
Charlotte as a resilient and healthy city 33
Charlotte as a city with opportunities for all 34

03 HOW CIRCULAR IS CHARLOTTE? 36

Understanding the current state 37
Exploring the context 37
Mapping the stakeholders 41
Understanding what happens with waste in Charlotte 44
Uncovering the potential of circularity 48

04 TOWARDS A CIRCULAR CHARLOTTE 52

Developing a strategy for a Circular Charlotte 53
Overcoming barriers to achieving circularity 54
Systems change for circularity 56
Short-term roadmap 66
Medium-term roadmap 68
Long-term roadmap 70

05 BUSINESS CASES 72

Developing business cases for Charlotte 73
Building a closed-loop textiles chain 74
Upcycling food waste into feed 78
Creating a materials innovation incubator and lab 82
Developing an incentivized reverse logistics system 86
Establishing city-wide circular concrete 90
Key takeaways 94

06 CONCLUSIONS AND NEXT STEPS 98

Reflection on a Circular Charlotte 99
Next Steps 101

BIBLIOGRAPHY 102
CREDITS 109

CIRCULAR TRANSFORMATION IN CHARLOTTE

INTRODUCTION

Nearly every turn you take as you walk through Charlotte's Uptown greets you with a new construction project of impressive scale. The city is in the middle of a building boom, adding everything from apartments to office buildings and hotels. While Uptown is sprouting expansions to its sleek skyline, neighborhoods like NoDa, a historic district once at the center of the city's textile manufacturing industry, are bursting with the addition of new microbreweries, restaurants, and arts venues.

This expansion of the city points to Charlotte's increasing popularity as a place to live and work. Charlotte is now ranked as one of the fastest growing metropolitan regions in the United States (7th out of 53), having increased in population by 13.9% between 2010 and 2017 (Thomas, 2018). Importantly, Charlotte was recently named the number one city for attracting millennials, demonstrating its position as a place of opportunity for launching a career and building a family (Abadi, 2017).

Beyond changing physically, Charlotte is undergoing a broader transformation in its character, evolving from a banking-focused city with a history of manufacturing and logistics, to a dynamic urban center with unique specialties in the high-tech industry. Though it is currently ranked as a "gamma-minus" city – the lowest tier on the Global Economic Power Index (GEPI, 2015) – these transformations position Charlotte to become more of a force in the international scene over the coming years.

With every new building and enterprise taking root in Charlotte, the city has a chance to reimagine its future and shape the values and principles that will define the next phase of its history. This growth is not only an opportunity to cash in on Charlotte's successes, but also to address challenges – those specific to Charlotte, and those we face as humanity at large. Investment brings with it the opportunity for creativity and innovation – as well as the development of new solutions that can become the basis for Charlotte's next wave of prosperity.

Building an inclusive, zero-waste economy

One of the largest challenges that Charlotte faces was highlighted in a now widely-cited study, published by the Equality of Opportunity Project, which examined economic mobility in America's 50 largest cities. With only 4% of people born into poor families in Charlotte successfully making it out of poverty in their lifetimes, Charlotte's performance was ranked last out of the cities evaluated (Chetty, 2017). Though the problem of low economic mobility is clearly severe in Charlotte, it is a challenge that many cities and countries around the world face.

The city's current phase of growth must therefore not only improve overall wealth: it must provide pathways for decreasing income inequality and increasing access to opportunity for all.

Devising structural solutions to these problems will not only benefit Charlotte, but potentially serve as an example to other parts of the world facing similar struggles.

This period of development also gives Charlotte space to take action on another key opportunity and moral imperative: the transition from a linear to a circular economy. The vast majority of our economic system can currently be defined as linear. We extract resources, use great amounts of labor, energy, and money to transform these into products, and then, soon after their use, these products get thrown away. Every time a product that we have crafted and manufactured with care ends up in a landfill, we lose its "embodied value." McKinsey estimated that up to 630 billion dollars a year are lost in Europe through the loss of materials in the linear economy (EMF & McKinsey, 2011).

This linear system is not only generating an enormous amount of waste and loss of value: it is also putting our way of life at risk. Certain critical resources, like the metals used in electronics, are becoming scarcer. The ecosystems that we rely on for essential environmental services (like the production of clean air and water), as well as the supply of goods (from food to building materials), are overexploited and at the point of collapse. As our economy continues to grow, our demand for these already overexploited materials continues to increase, exacerbating these issues. We need to transition to a smarter model of resource management, where instead of getting lost, these valuable materials are kept in perpetual circulation, reducing the need for increasingly scarce or hard-to-extract virgin materials.

Our dominant economic model, though it has historically brought much prosperity, has now reached a point of diminishing returns.

Though it continues to generate value and prosperity, it does so at the expense of an increasing socio-economic divide and contributes to the destruction of natural capital that is essential for its own continuation. The circular economy – a new economic system that is regenerative and waste-free by design – can not only eliminate negative impacts and create new sources of value, but can also be used to bridge the wealth divide and create new pathways for upward mobility in Charlotte.

Within a circular economy, products and materials are circulated at high value for as long as possible, extending the life of products and enabling high-value component and material recovery for reuse or recycling. The systemic transformations involved in a circular economy – from the development of new technologies, to the evolution of new forms of collaboration and new business models – have also been shown to have great potential in generating new employment and skill development opportunities.

Circular Charlotte

Charlotte is the first city in the United States to make a commitment to adopting the circular economy as a public sector strategy. In its circular future, all of the material resources that now end up in landfills will be the basis for Charlotte's next industrial revolution: the foundation for an era of green manufacturing that unlocks new technological advances and increases local resilience and productivity.

This study, commissioned by the city of Charlotte and Envision Charlotte, helps lay the groundwork for the city's transition to circularity. In it, we describe the results of a baseline analysis of Charlotte's current circular economy performance, including the total value of resources wasted in the city. Together with inputs from stakeholders throughout the city, we have drafted a vision statement for what a circular Charlotte could look like, and created a set of metrics – Key Performance Indicators – that can be used to track the city's progress. Lastly, we present an initial roadmap and a selection of high-impact business cases that can already be implemented within the city in order to move towards a circular economy.

The results presented here are just the first step in a long journey. Though the first step is often the hardest, it is also the most important: it signals a commitment to move towards a greener, healthier, and more equitable future for Charlotte and its people.

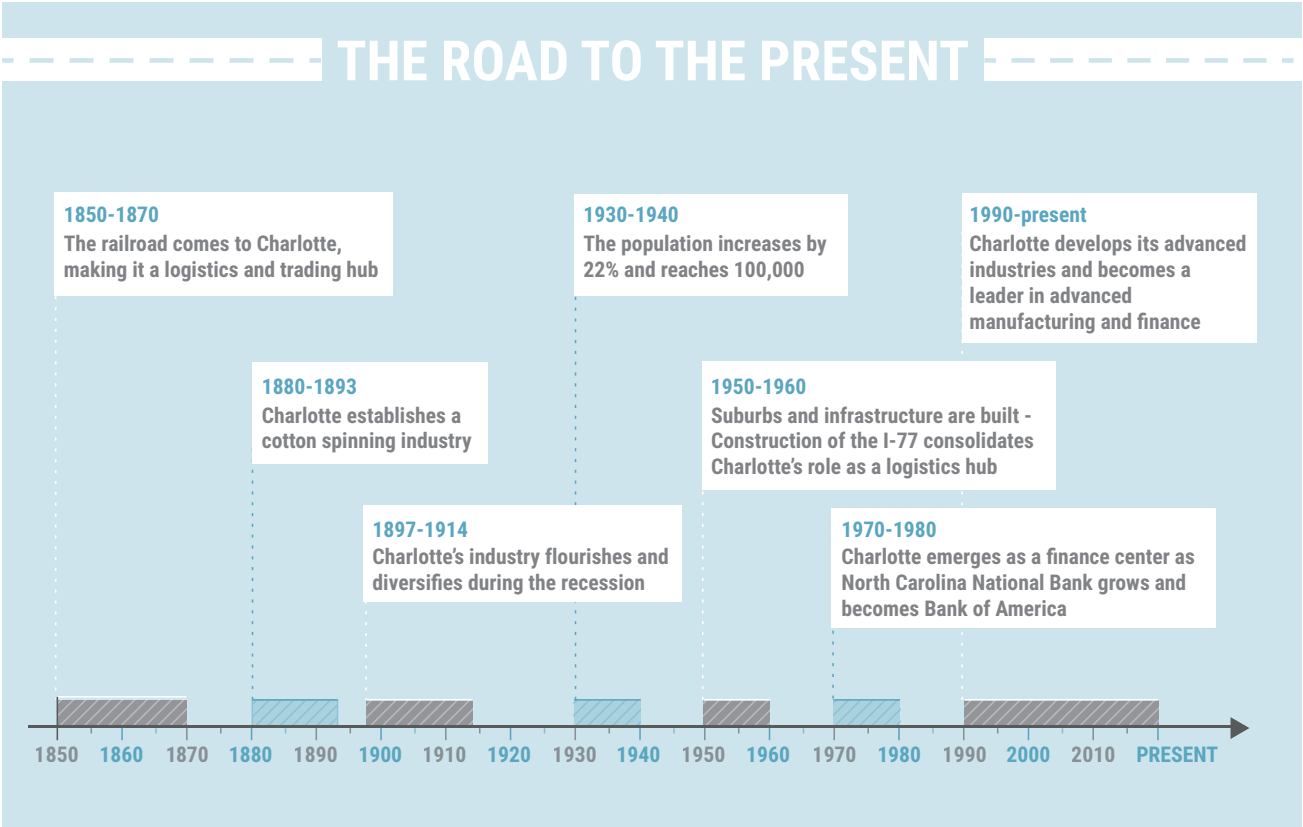


Figure 1. The Road to the Present

THE CITY OF CHARLOTTE

The city of Charlotte, known as the Queen City after its eponymous German princess, Charlotte of Mecklenburg-Strelitz, was incorporated in 1768 and settled by an initial wave of Irish migrants. Though the basic grid network of Charlotte's Uptown was already laid out by surveyors in 1770 in anticipation of further development, at that point the town only consisted of a handful of log houses.

In 1799, gold was struck in nearby Cabarrus County, setting off the first American gold rush and making North Carolina the leading state for gold production until the opening of mines in the western states. As more veins of the precious metal were discovered, the Charlotte Mint was founded to locally melt and coin the gold. Despite these developments, Charlotte remained a relatively small town, and only experienced its first significant growth phase after the Civil War, when a combination of factors led to Charlotte's emergence as one of the South's primary centers of activity.

Financed by prominent Charlotte-area businessmen, the Charlotte and South Carolina Railroad began operating in 1852. This line played a critical role in the emergence of Charlotte's textile boom in the late 19th and early 20th century, when the city became a watershed for cotton produced in North Carolina and neighboring states. Cotton mills sprung up throughout the city and workers flooded in to process the material into new high quality products such as textiles, clothing, and furniture. To support this new boom in commerce, logistical connectivity continued to improve, making Charlotte into one of the most well-connected hubs in the country. In 1910, Charlotte surpassed Wilmington to become the largest city in North Carolina, reaching a population of 34,000.

Pioneering character

Charlotte's prosperity has historically been driven by a spirit of risk-taking and innovation, informed by the acuity of its people in paying attention to the technological trends of the time. While other neighboring towns rejected the idea of having a railroad because it would be too noisy and polluting, Charlotte embraced this leap into the future. The drive to stay on top of the latest trends began with Charlotte's railroad and first cotton mills and continues into today's aerospace and electronics manufacturing industry.

While other cities have struggled, and buckled, under the pressure to outsource their local industries, Charlotte has maintained and diversified its existing capacity and infrastructure. Today, manufacturing represents about 30% of the regional economy and employs 144,000 of Charlotte's citizens (Charlotte Chamber, 2015). With the presence of some of the world's biggest furniture and textile companies, traditional manufacturing is still going strong in Charlotte, but the city has continued to diversify and enhance its capabilities in areas such as energy technology, aerospace technology, precision metrology, and specialty chemicals and plastics.

CHARLOTTE: A GREAT PLACE TO BE

- ***Attractive to businesses:*** *7th on Forbes list of Places for Business and Career (Forbes, 2018)*
- ***Job opportunities:*** *Unemployment below state average at 3.4% (Bureau of Labor Statistics, 2018)*
- ***Wealthy:*** *$53,000 GMP (global metropolitan product) per capita - 61st wealthiest metro (Parilla, 2016)*
- ***Livable:*** *26th most livable city in US (24/7 Wall St., 2017)*
- ***Hotspot for young people:*** *Number one choice for millennials in 2015 (Abadi, 2017)*
- ***Clean:*** *Among the least polluted cities in US (American Lung Association)*

THE STRENGTHS OF CHARLOTTE

- ***Specialized in advanced industry:*** *7th in growth of advanced industry from 2013 to 2015 (Mecklenburg County Community, 2018) - 8.9% of Charlotte's workforce is employed in advanced industries (2014) contributing to 17% of GMP*
- ***Strong manufacturing sector:*** *The manufacturing industry represents about 30% of the regional economy and employs 144,000 citizens in Charlotte (Charlottechamber, 2015)*
- ***STEM jobs:*** *The Charlotte metro has a high demand for STEM occupations, especially in middle-skill jobs, helping maintain attractiveness for workers (Parilla, 2016)*
- ***Globalized economy:*** *14% of GMP in 2014 provided through export (110,000 jobs in Charlotte supported by export) and 6.8% employment at global firms*
- ***Well connected:*** *45 million passengers per year in Charlotte Douglas International Airport, placing it 24th globally. 27,000 miles of rail connects Charlotte with 23 states*

Charlotte's industrial success has translated to high levels of prosperity. The city is ranked 7th on Forbes' list of Places For Business And Career, has an average household income of $56,731 (Forbes, 2018), and an unemployment rate below state average at 3.4% (Bureau of Labor Statistics, 2018 - April). Across various metrics, Charlotte is doing significantly better than other cities in the same weight class.

Partly resulting from this prosperity, Charlotte developed another major role as a prominent banking center in the 1970s and 80s. The city is home to the headquarters of Bank of America, and to the secondary headquarters of other major banks like Wells Fargo, making Charlotte one of the largest centers of banking activity in the United States, second to only New York City (Roberts & Rothacker, 2017).

As evidenced by the current construction boom, Charlotte has become a popular destination for young and highly educated professionals looking for a place to advance their careers (Fahey, 2016), and has been recognized for its high quality of life and livability (Stebbins, Comen, & Sauter, 2017).

Areas for improvement

In the midst of this account of Charlotte's successes, there is another story that until recently remained largely untold. Despite being a wealthy city with a generally high quality of life, Charlotte has more than 148,000 people living in poverty (DATA USA, 2018). In several neighborhoods, more than half of the residents are living below the poverty line (Off, 2016). Looking at a map of Charlotte's average income per neighborhood shows how dominant this social divide is in the city's geography, marking a physical rift across the city. Combined with the recent findings on Charlotte's low social mobility (Deruy & Boschma, 2016), this paints a picture of a city where 13.4% of the population is currently left behind. Tensions resulting from this social divide have justifiably added to local discontentment, and can be linked to events such as the riot of 2016, which put Charlotte in the international media spotlight.

Another barrier to Charlotte's development has to do with demand for highly skilled labor in science, technology, engineering, and mathematics (STEM) fields. There are not enough local graduates with these skills to fill local demand. This makes Charlotte attractive for graduates from other parts of the country, but can also slow down tech development as these hiring needs go unfulfilled for longer periods of time (Parilla, 2016). Potentially connected to this low number of STEM graduates is the fact that Charlotte is lagging behind on key metrics related to innovation and new business, as highlighted below:

- Lowest social mobility among the 50 biggest cities in the US (Deruy & Boschma, 2016)
- More than 148,000 people living in poverty (DATA USA, 2018)
- Shrinking middle class (Mecklenburg County Community, 2018)
- Low investment in R&D - behind similar cities with a factor 20 or more (Parilla, 2016)
- Patenting is increasing but still below other cities (Parilla, 2016)
- 25th out of 40 in Kauffman Foundation 2015 Startup Activity Index
- Lower amount of venture capital compared to other cities
- Not enough local graduates to support local demand for educated labor - a large share of employment is covered by immigrating graduates (Parilla, 2016)

The path ahead

Charlotte clearly has the wind in its sails and is poised for continued growth. However, to genuinely seize the opportunity to become a more visible participant in the international community of cities, it still needs to tackle some central challenges, among which, we identify:

1. Creating a unique and progressive brand for the city and its business environment to consolidate its position as a city of the future.
2. Improving the resilience and livability of the city to continuously make it a safe and attractive home for its citizens.
3. Closing the social divide and formulating a vision for the city that unites all social groups.
4. Becoming an international example of how economic and industrial development can progress in a sustainable and circular manner.

A pathway forward that can address all of these issues is the transition a circular economy.

THE CIRCULAR ECONOMY

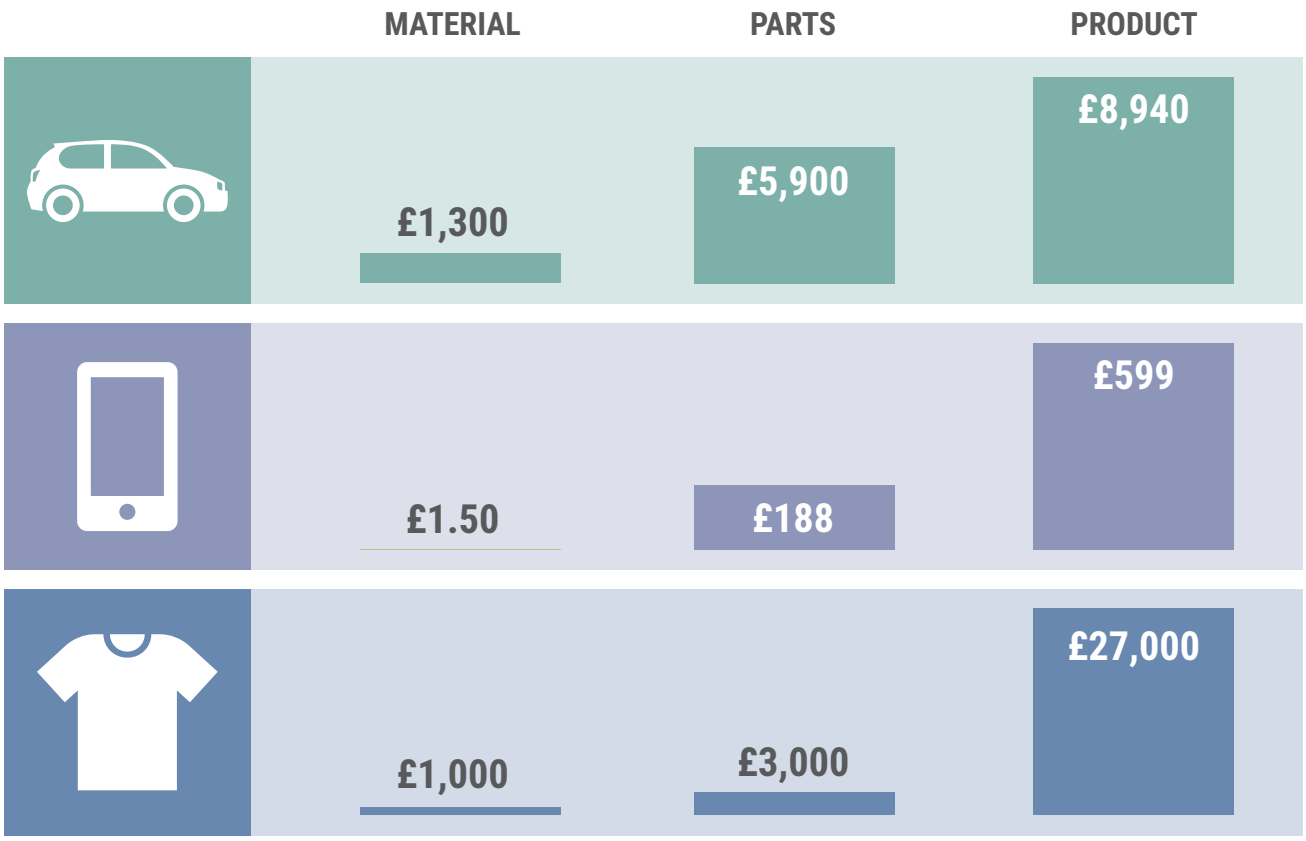
We now live in what has been described as a linear economy, where we extract many biotic (e.g. plant or animal) and abiotic (e.g. mineral or metal) resources, use them, and then send them to a landfill or disperse them into the environment in a way that they are unrecoverable – for example, through incineration, spraying of chemicals, or the use of products like paints that are not designed for recovery. Less than 10% of the materials that pass through our economy each year are recycled (Haas, Krausmann, Wiederhofer & Heinz, 2015).

Moving towards a "circular economy," which is broadly defined as an economy that is regenerative and waste-free by design, presents vast potential for financial gains made possible through the reuse of all raw materials that are currently lost in the linear "take, make, dispose" system and by extending the value-generating life cycle of products. This transition can be supported through alternative business models and purchasing patterns that will structurally support the recovery of materials, such as leasing models and advanced approaches to extended producer responsibility (systems that make product manufacturers responsible for what they create and sell, even after the products are sold).

Preserving complexity yields more value

One of the principles of the circular economy is to preserve complexity to the greatest extent possible. As illustrated in Figure 2, the value of a product is much higher than the value of its individual parts, and the parts are much more valuable than the base materials they are made of. In an ideally circular system, products are designed for easy repair and refurbishment, so they can go through multiple cycles of use before they need to be taken apart. Once they can no longer be repaired, products should ideally be designed for disassembly, making it possible to harvest their components for high-value resale. Finally, when no more value can be extracted for these elements, all materials should be recycled at high quality (without mixing or downgrading them to lower uses).

A parallel to this value cycle can be seen in the amount of employment generated through circular practices at different levels. The US EPA and the Institute for Local Self Reliance estimate that low-value activities that result in material losses (like incineration and landfilling), only generate a handful of jobs per 10,000 tons of used goods. Recycling generates an order of magnitude more, but reuse and refurbishment are by far the winners, with almost 300 jobs created.



Finished products are worth much more than the raw materials inside them.

Figure 2. Creation and preservation of value along the product chain - adapted from Benton & Hazell, 2013

JOB CREATION POTENTIAL
per 10,000 tonnes of used goods

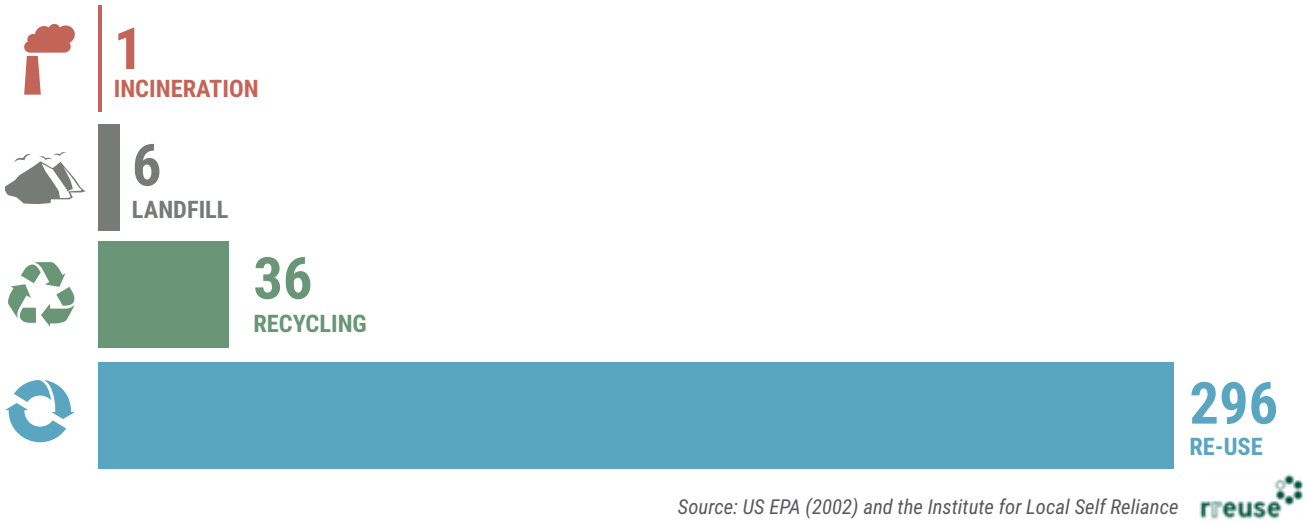


Figure 3. Job Creation through reuse

Implementing a Circular Economy

Though there are many definitions of the circular economy (a recent literature review looked at 114 variations), there are some core traits that most people think of when they hear the phrase. Often, we use analogies with natural systems to explain how such an economy could look: when you're walking through a forest, there is no real "waste" generated. There may be leaves on the ground or fungi feasting on fallen trees, but everything is part of a cycle that reabsorbs these resources back into high-value use. The basic principles of designing an economic system based on this model initially seem straightforward, and include:

- Design all products for easy repair, disassembly, and full recyclability.
- Create the necessary business structures and incentives to get these materials back into the economy at their highest possible value (preferably as whole products or components).
- Strive to use only responsibly-sourced renewable resources for both energy and material provision.
- Avoid the use of toxic substances that may continue to circulate in our environment.

When applying this circular approach our own economy, however, we quickly run into the realization that not all options for closed-cycle resource management result in an optimal outcomes. If we use more oil to recycle plastic bottles than we would use to create new bottles, this is not a circular solution. If we overharvest available natural resources, leading to the destruction of ecological productivity in our agricultural landscapes, likewise, we have damaged the regenerative basis on which our ideally regenerative circular economy should rest. Furthermore, if our recycling practices are dangerous and lead to health impacts for individuals, then the fundamental point of the system, which is to facilitate a healthy and equitable society for all, is called into question.

Therefore, there are several other parameters we need to consider when aiming for circularity. Yes: we want to manage our resources so that they can cycle infinitely at high value. But: we must do so without undermining our natural capital, creating stresses on Earth systems like the climate, leading to social inequities, or threatening the health and wellbeing of humans and other animals. Therefore, from an integrated perspective, a circular economy is one where we maximize the value generated from resource cycles without undermining the functioning of the biosphere or the integrity of human societies. Activities in the economy should be therefore judged on how well they support this ultimate outcome.

The circular economy is a new economic model for addressing human needs and fairly distributing resources without undermining the functioning of the biosphere or crossing any planetary boundaries.

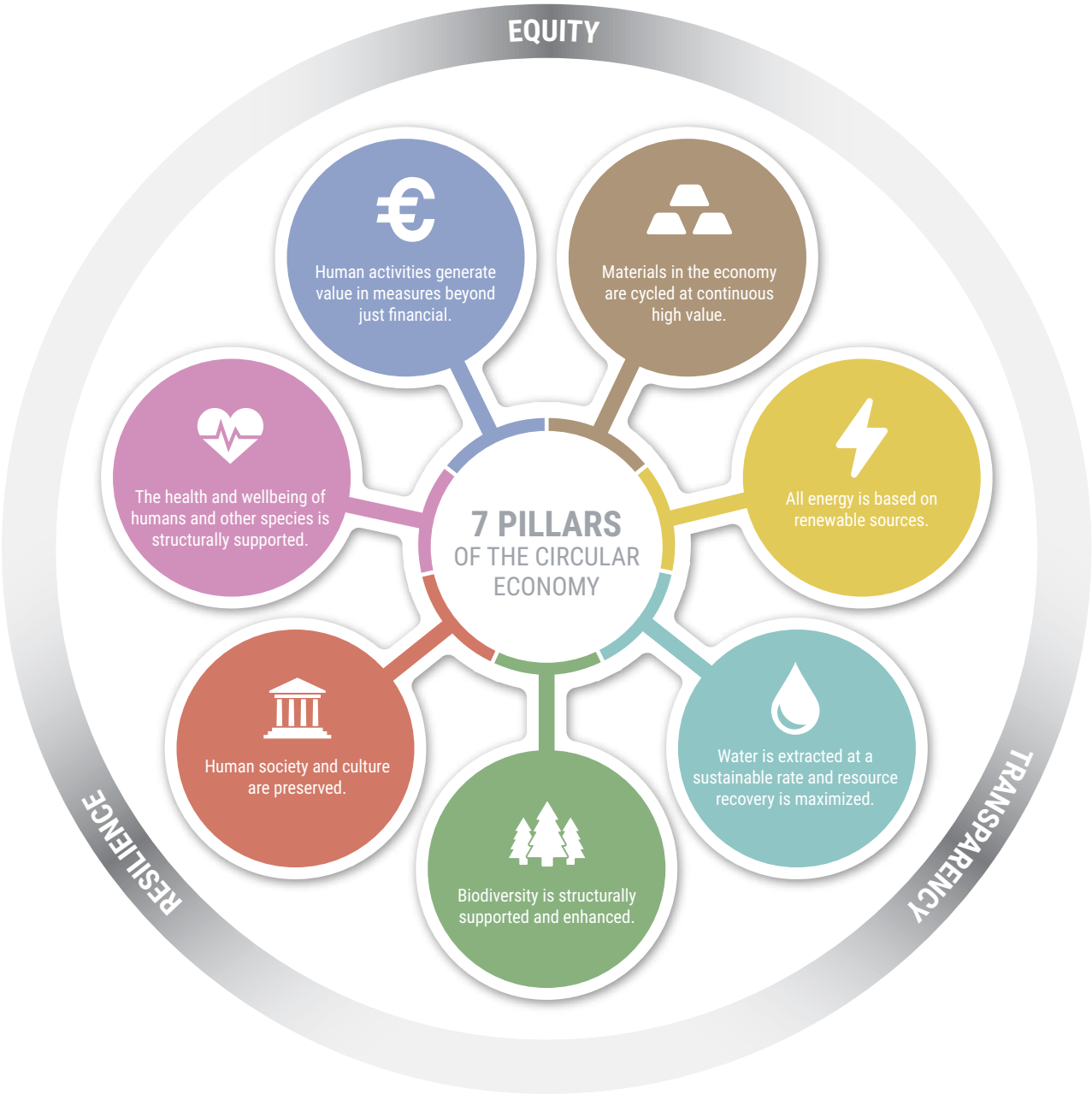


Figure 4. Seven Pillars of the Circular Economy

Seven Pillars of the Circular Economy

Figure 4 illustrates Metabolic's "seven pillars" framework for evaluating circularity. These seven pillars capture the areas that must be simultaneously considered when looking at whether certain activities are genuinely circular. We need to evaluate all of our actions not just on one parameter, but on a complete spectrum. With a holistic set of performance indicators, we can track whether or not circular activities are leading to better results across a broad range of impacts, rather than just optimizing for high value material recovery at the expense of other areas of performance.

To achieve real progress towards a circular economy, it is clear that we need new incentive structures, new business models, and new ways of evaluating our economy to assess whether it is functioning within the safe limits of Earth's carrying capacity. By shifting from the current linear economy to the circular is fundamentally difficult as it challenges many structures and mindsets that are considered common sense but it also holds the potential to unlock formerly wasted value and spark new innovative solutions. Most importantly, the circular economy offers a way to structure the economy in such a way that it can continue to prosper well into the new century as resources are getting scarcer and demands continue to rise.

VISION FOR A CIRCULAR CHARLOTTE

DEVELOPING A CIRCULAR VISION

If we take these high level ideas about the circular economy and actually apply them to Charlotte, what might the city actually look like in a circular state? Here we envision some of the changes that might take place within Charlotte if it achieves the full spectrum of a circular economy. We have organized the vision around four thematic areas:

1 Zero Waste City

2 Innovative City of the Future

3 Resilient and Healthy City

4 City with Opportunities for All

Though some of these ideas may seem farther off in the future than others, every plan starts with imagining the reality we aim to achieve. The picture we describe here, from a 2050 perspective, will certainly not be a perfect reflection of what actually transpires, but it can provide a starting narrative and inspiration for the next decades of Charlotte's development.

CHARLOTTE AS A ZERO WASTE CITY

In 2050, Charlotte can proudly call itself a Zero Waste City. Back in 2018, when the Charlotte set off on its transition path, less than 12% of its solid waste was recycled or composted – and many of the recycling methods used at that time would not even qualify as recycling today. The majority of the city's solid resources were put into low-value applications (i.e., downcycled), like cement being used as road-filler.

Today, 98% of all residual materials are separately collected, and only the 5% of waste that is too low quality or hazardous to otherwise process is incinerated for energy recovery. The incineration facility opened in 2029, just a couple of years before Charlotte celebrated the permanent closure of its landfill, which ceased operating because the volumes of waste were too low. The small incinerator has been built to such high emissions standards that the air it releases is even cleaner than the ambient air. The amount of hazardous waste generated in the city is still decreasing each year as old stocks of products are slowly replaced with ones that have been designed based on circular principles.

Throughout the city, each household is equipped with smart sorting containers that simplify the process of separating different materials. The containers' built-in technologies tell users if they have sorted something incorrectly. However, the incentive to properly sort resources is already very high: for every pound of correctly sorted waste, residents get Charlotte Coins paid directly into their digital wallets. They can use their earnings for the purchase of local goods branded with the Circular Charlotte label, many of which have been remanufactured or grown from those same residual streams. If they have Charlotte Coins left over, they can also use them to pay for their – fully renewable – energy bill, or even pay their taxes.

A real-time resource monitoring platform, the Charlotte Circularity Dashboard, continuously reports how much is available of different kinds of residual goods – from citrus peels to old shoes. These resources are automatically diverted to various processing facilities throughout the city, run by large companies and small entrepreneurs alike. The Dashboard keeps a record of orders placed requesting different materials, and ships off materials to the earliest bidders. Because of Charlotte's strong position as a logistics hub, the city also accepts and processes many materials from the nearby counties, adding to the base of resources used for local manufacturing.

But before anything is ever disposed of in Charlotte, it gets the royal treatment of repair and refurbishment, maximizing its usable lifespan. The Innovation Barn, the city's center for circular innovation, is one of the busiest places in the city, with cafes serving food from the building's greenhouses, and with many different stores featuring upcycled products. It is also a center for experimentation and education, with many specialized repair facilities and workshops. New circular ideas are piloted at The Barn, and then scaled up in many other parts of the city. The Barn has also led to a completely different social dynamic than existed in the 2010s, when the main options available for spending time with friends involved eating or drinking at a café or bar. People come to the Barn to learn new skills, but also to socialize while repairing their own clothes or trading their old furniture in for something new.

CHARLOTTE AS AN INNOVATIVE CITY OF THE FUTURE

With Charlotte's innovations in waste collection and sorting, which resulted in the supply of previously-unavailable high-quality and pure resource streams, a whole new cluster of industries began to develop throughout the city. New product development exploded in the early 2020s. At first, the major focus of R&D activities was on processing textiles, plastics, and construction wastes. In 2023, CharM, the city's newly opened materials lab, a joint project of several of Charlotte's incubators and accelerators, began experimenting on how to convert collected bio-wastes into new materials – like clothing, furnishings, and biodegradable packaging.

Later, it became clear that complex consumer goods like household appliances could also generate more value in this new economy. Manufacturers discovered that they could actually claim financial benefits for every pound of materials that was successfully harvested from their products – provided that they included an RFID tag that could be scanned at the automatic sorting and disassembly unit newly installed at the city's Materials Recovery Facility (MRF).

The strong need for materials and product innovation because of the city's ambitious circularity goals also led the University of North Carolina Charlotte to establish a new educational facility, the Charlotte Institute of Circular Design and Engineering (CICDE). CICDE is now one of the top engineering schools in the world, attracting the brightest minds from throughout the U.S. and abroad. Charlotte is now broadly recognized as one of the world's most innovative design centers, and has pioneered the emergence of circular products that are now dominant in global supply chains.

As engineering and design became a central part of Charlotte's higher education scene, primary and high school curricula were updated to include more experiential learning opportunities and a unique mentorship program that paired up students with researchers. Most high school students now go through an internship at one of the many tech companies in Charlotte's burgeoning startup scene.

These new industries have transformed Charlotte's local economy, creating thousands of new jobs, boosting the city's resilience, and serving as an example for other cities around the world. The Circular Charlotte brand helped the city consolidate its leading position globally, and cemented Charlotte's top position in global rankings such as the Sustainable Cities Index. Barely a week passes without an international delegation coming to visit the city and learn from its successes.

CHARLOTTE AS A RESILIENT AND HEALTHY CITY

Back in 2018, at the start of Charlotte's transition to circularity, North Carolina was importing a net value of 47.4 million dollars' worth of commodities each year. China had just closed its borders to lower-quality recyclables, leaving countries around the world struggling with the challenge of processing huge volumes of unwanted material. The drive for innovating towards circularity was not just a matter of principle: it was equally grounded in economic opportunity and the need for greater local resilience.

Since circular building standards became the norm, new buildings in Charlotte are designed for complete disassembly. They are demolished by highly trained demolition teams with the help of efficient robots, who scan all individual building components and register them on the Charlotte Circularity Dashboard. The city is now able to harvest a large fraction of the materials needed for new construction projects from within its own demolition cycle, and has in this way eliminated around 30% of the material that used to go to landfills.

As other circular industries developed, Charlotte and its surrounding region became increasingly independent of foreign imports, with almost all material sourced from local cycles. Even local food production has grown immensely, with the advancement of vertical farming technology and the reuse of organic waste streams as fertilizer. Most of Charlotte's schools now also have their own small-scale aquaponics facilities, which are used both for hands-on science education as well as to provide farm fresh produce and fish to the schools' cafeterias. Further efforts to increase the city's health and resilience have focused on the decentralization of certain utility services. Renewable energy, decentralized battery storage, and smart distribution of energy through the city's smart grid have made Charlotte's energy system highly resistant to the impact of storms or floods, with most damage remaining localized.

Circular Charlotte also became dramatically greener as nature-based solutions became an increasingly central element in the design of buildings and public places. The most dramatic change only happened recently, in 2037, when the municipality finally did away with all personal vehicle transport in the inner city. All the asphalt roads were converted into green boulevards, with walkways meandering among trees and flowers, lined with miles of well-connected bike paths. At the center of each boulevard are rail-lines for the public transport vehicles, which can be ordered on command from any part of the city. They are driverless and each have several seating compartments, allowing people to be picked up and delivered efficiently to their final destination. The parking lots which once dominated Charlotte's Uptown have all been replaced with either public green spaces or new mixed-use developments, further improving the walkability and "human-scale" of this busiest part of the city. People's overall health has improved as a natural result of more walking and biking, not to mention the drastically improved air quality. The city's canopy of trees, which was under threat in 2018 due to increased tree removal relative to new planting, has never been as dense as it is today. Charlotte is one of the greenest cities in the US, known to some as an example of an urban forest.

CHARLOTTE AS A CITY WITH OPPORTUNITIES FOR ALL

Though Charlotte now has less than 0.5% of its population living in poverty, at the start of its journey towards a circular economy, this was far from the case. For this reason, initial efforts on establishing circular industry and innovation were largely focused on skill development, training, and inclusive programs designed to lift up those who were economically disadvantaged.

In 2019, the city's solid waste department established a test rehabilitation program for the homeless community, providing employment in plastic waste sorting and remanufacturing. Plastic wastes, which were of too low a quality for automated processing at that time, were sorted, washed, and shredded for the production of small batches of local products like street furniture, waste bins, and trophies for school sporting events. Some of trainees involved in the pilot program went on to start their own companies focused on recycling and product manufacturing.

In a similar effort, local culinary schools, like the Community Culinary School of Charlotte and the Culinary Program at the Art Institute of Charlotte, collaborated to set up a program focused on the establishment of circular businesses in the food sector. Successful projects resulting from this effort include a 5-star restaurant that uses food salvaged daily from grocery stores to produce gourmet meals, a farm-restaurant hybrid where all food served is produced on site in vertical agriculture systems, and a food processors cooperative making soups, sauces, and jams out of produce rejected at retail stores because it failed to meet aesthetic rather than safety standards.

From the very start of Charlotte's shift towards a circular economy, the Goodwill Opportunity Campus, already a community fixture, has played an essential role in mainstreaming and supporting circularity efforts. In 2019, the Campus, launched a new range of circular training programs focused on repair and remanufacturing skills, which resulted in a slew of new store openings and services within the city. In addition, the Charlotte Chamber of Commerce launched support services for new entrepreneurs and local makers, giving advice and providing resources for people launching businesses. All local products made or refurbished according to circular principles can be labeled with the Circular Charlotte brand, which has been an important marketing platform for small enterprises in the city, particularly in their early stages.

Another effort towards improving quality of life and increasing access to opportunities has been the development of circular housing in Charlotte. As part of the housing boom of the 2020s, the city of Charlotte began to encourage inclusive development by giving priority to developers who aimed to include different price levels of housing within individual developments. Not only did this effort increase the social cohesion of neighborhoods, as young couples were able to stay in their neighborhood as their income levels rose, but it also created an equitable manner of providing lower-income housing in prime locations throughout the city.

A uniquely circular feature of many of the new housing developments was the emergence of "full service living" concepts. When you rent or buy a house, you can select from a range of equipment, furniture, and transport packages - like access to cars or bikes, giving you permanent access to the most efficient and up-to-date appliances and equipment. The companies providing this equipment get a steady income stream from the rental of their products, but also have the incentive to design these products for refurbishment and recycling, since they remain responsible for the full lifecycle of their equipment. The new full-service housing concepts have reduced the total amount of large household goods thrown out in the city, and has made moving – especially for students and people starting out their careers – much more carefree.

MEASURING CIRCULARITY

The vision imagined in the previous section shows one of many ways that Charlotte could develop as it progresses towards a circular economy. Regardless of the exact path that the city and its residents choose to travel, there are certain performance outcomes (like eliminating waste sent to landfill) that should ultimately be achieved in a circular model. To help understand these performance outcomes, and make the transition to circularity tangible and actionable, we have translated the vision into concrete goals and key performance indicators (KPIs) that can be used to measure Charlotte's progress towards circularity. As with the vision itself, these must be holistic and cover not only the physical reality of achieving circularity (resource cycling, impact reduction, etc), but also cover the auxiliary benefits of circular activities (such as employment, innovation, and health) to ensure that the strategy is implemented in a way that also increases value and equity for society.

These goals and KPIs have been developed based largely on inputs from the City of Charlotte and other stakeholders over the course of two stakeholder sessions. They are organized across the same four thematic areas that we have used to define the vision for a Circular Charlotte.

On May 24th, we hosted a stakeholder workshop with entrepreneurs, universities, city representatives, etc. to understand community priorities on moving towards a circular economy and to help shape the vision for a Circular Charlotte.

To illustrate the holistic nature of the goals and KPIs, the KPIs are linked to our seven pillars of the circular economy framework (plus three overarching categories), which is described on page 13. The following legend shows the icons used to represent each of the pillars and overarching categories.

CHARLOTTE AS A ZERO WASTE CITY

GOALS: CHARLOTTE AS A ZERO WASTE CITY	KPIS: CHARLOTTE AS A ZERO WASTE CITY
1. Charlotte terminates all use of landfills by 2040	Tons of waste going to landfill annually per capita
2. Charlotte improves its virgin (new) resource efficiency	Tons of virgin resources consumed by industry per $ gross metropolitan product (GMP)
3. Charlotte minimizes annual GHG emissions to 2 tons per person by 2050	Tons of CO_2 equivalent greenhouse gas (GHG) emissions per person
4. Charlotte recovers maximum value from waste streams	Average profit per ton of recovered waste
5. Charlotte maintains material quality (complexity) of resources	Percentage of resources recycled at the same level of quality/complexity
6. Charlotte ensures that nutrients from all organic wastes are returned to natural cycles	Percentage of organic waste processed to recover nutrients and return them to soil
7. Charlotte reduces its reliance on critical (scarce) materials	Tons of critical (scarce) materials consumed by industry per $ GMP
8. Charlotte improves information flows on waste between stakeholders and the City	Qualitative assessment of the quality of information flows
9. Circular companies can thrive in Charlotte	The number of circular businesses as a share of total businesses

Highlighted KPI

Tons of waste going to landfill annually per capita = WL/C

Charlotte

Source: Envision Charlotte, 2017

Austin

Source: Austin Resource Recovery Master Plan, 2011

CHARLOTTE AS AN INNOVATIVE CITY OF THE FUTURE

CHARLOTTE AS AN INNOVATIVE CITY OF THE FUTURE	KPIS: CHARLOTTE AS AN INNOVATIVE CITY OF THE FUTURE
1. Charlotte encourages cleantech (impact-reducing technologies) startups	Number of companies in the cleantech (impact-reducing technologies) sector as a share of all companies
2. Charlotte is a world leader in developing, testing and scaling new technologies relating to the circular economy.	Total revenue from the cleantech sector in Charlotte as a share of GMP
3. Charlotte encourages innovation in material intensive sectors (manufacturing, logistics, transportation and waste treatment)	Charlotte's share of U.S. patents in material-intensive sectors
4. Charlotte is a playground for developing and testing innovative circular solutions	Number of sustainability related pilot projects launched in Charlotte
5. Charlotte supports sustainable and circular R&D and innovation	Share of public funding for R&D going to sustainable and circular innovation
6. Charlotte supports bottom-up community initiatives on sustainability and circularity	Number of community initiatives related to sustainability or circularity supported by Charlotte per 10,000 capita

Highlighted KPI

Charlotte's share of U.S. patents in material-intensive sectors (manufacturing, logistics, transportation and waste treatment)

Charlotte

0.44%
U.S. patents

Austin

2.04%
U.S. patents

Source: U.S. Cluster Mapping Project, 2015
Calculation: https://docs.google.com/spreadsheets/d/1XqqRWADsz_RJ1_73aUySGtBkBs3Tf_b3aiqEkcmT768/edit#gid=585323749

CHARLOTTE AS A RESILIENT AND HEALTHY CITY

GOALS: CHARLOTTE AS A RESILIENT AND HEALTHY CITY	KPIS: CHARLOTTE AS A RESILIENT AND HEALTHY CITY
1. Charlotte has clean water and air and a low exposure to pollutants	Pollution levels (NO_x, PM_{10}, $PM_{2.5}$, BOD, QALY)
2. Charlotte has high quality and extensive green areas	Share of area of green spaces in the city of Charlotte
3. Charlotte provides equal access to green areas for all citizens	Percentage of residents living within 5 min walking distance to green space
4. Charlotte has resilient systems of provision (food, energy, water, etc.)	Self-sufficiency (local production as a share of total consumption of food, energy, water)
5. Charlotte minimizes flooding risk	Flooding risk
6. Charlotte minimizes the use of toxic substances in industry	Use of toxic substances in industry in ton per $ GMP
7. Charlotte ensures access to healthy food for all	Percentage of households with food insecurity
8. Charlotte promotes social cohesion and strong communities	Share of population attending community events or involved in community organizations

Highlighted KPI

Share of area of green spaces in the city of Charlotte

Charlotte

Park land as Percent of Adjusted City Area

4%

Rank 97/100
ParkScore Index

Phoenix

Park land as Percent of Adjusted City Area

16%

Rank 56/100
ParkScore Index

Source: Trust for Public Land's ParkScore index, 2017

CHARLOTTE AS A CITY WITH OPPORTUNITIES FOR ALL

CHARLOTTE AS A CITY WITH OPPORTUNITIES FOR ALL	KPIS: CHARLOTTE AS A CITY WITH OPPORTUNITIES FOR ALL
1. Charlotte ensures the unemployed have the right type of training/experience to have meaningful circular jobs	Amount of training/experience relevant to circular jobs among the unemployed
2. Charlotte ensures employment opportunities for all	Unemployment rate
3. Charlotte offers meaningful jobs that are tied to the circular economy	Total number of circular job vacancies
4. Charlotte has circular jobs that provide opportunities for economic mobility	% change in number of people homeless, unemployed, or living in poverty compared to 5 years previous
5. Charlotte ensures that circular economy strategies are leveraged to alleviate social inequality	Inequality index
6. Charlotte empowers citizens to reduce material consumption and reuse/recycle their materials and goods	Percentage of population that has access to tools, infrastructure, and knowledge they need to reduce material consumption, and recycle or reuse materials and goods

Highlighted KPI

Unemployment rate

Charlotte

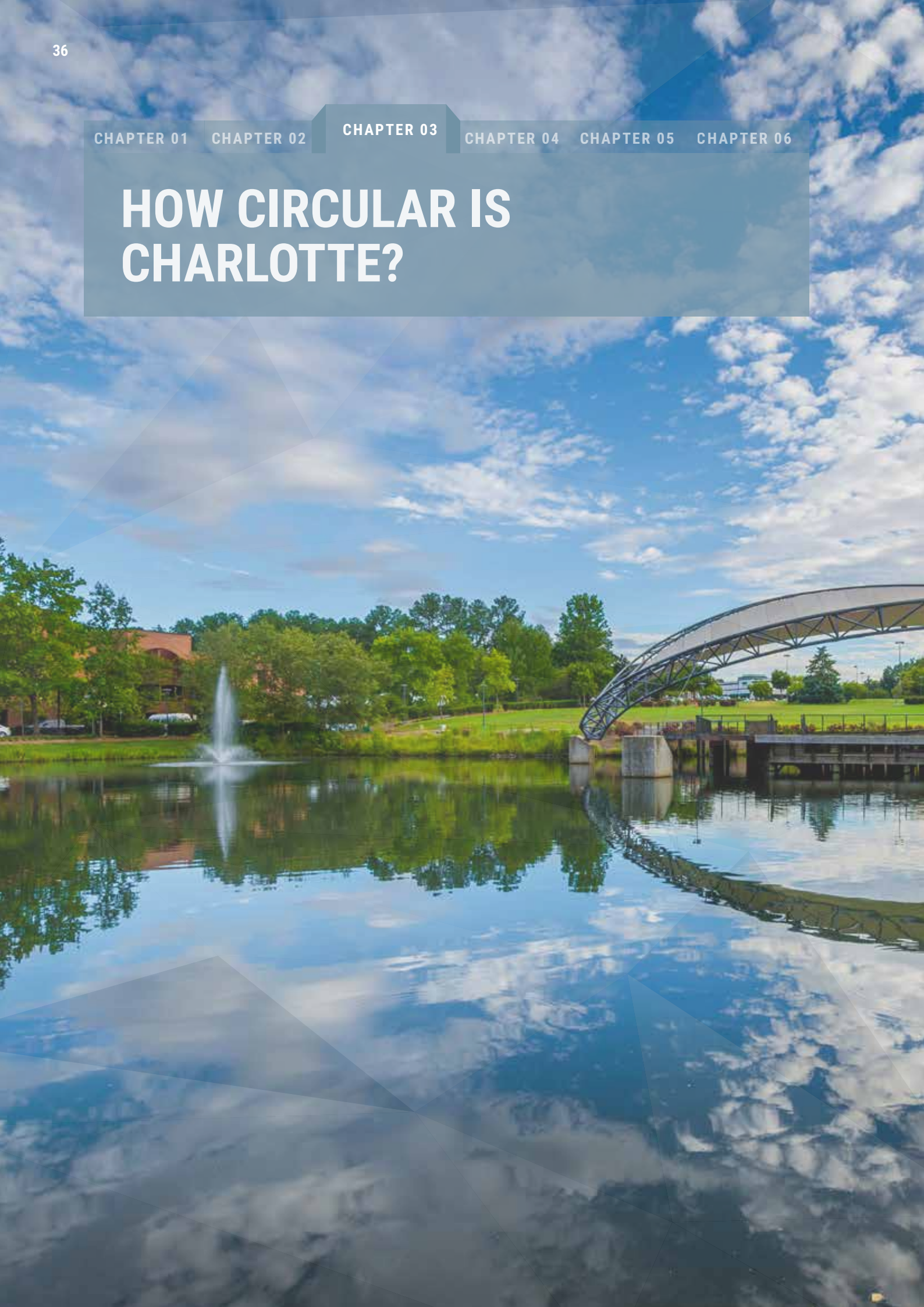
3.4%
Unemployment rate

Phoenix

3.8%
Unemployment rate

Bureau of Labor Statistics (2018) for April 2018

HOW CIRCULAR IS CHARLOTTE?



UNDERSTANDING THE CURRENT STATE

In order to create an effective strategy for Charlotte around the circular economy, we started by first building an understanding of the way things are currently functioning through a baseline assessment of the context, stakeholders, waste flows, and economic and social potential of wastes. This chapter provides an overview of the results from this first baseline assessment as a starting point.

The economic and environmental outcomes we see in Charlotte result from the structures (e.g. social, economic, political, physical) and the actors working in Charlotte. In the first two sections of this chapter, we provide a bit of background on the story of waste in Charlotte, looking at the context and the stakeholders active in the city.

This is followed by a material flow analysis, which provides a big picture view of where a large share of the wastes in Charlotte are coming from, what they consist of, and what is happening to them (e.g. landfill vs. recycling or composting). As we collected data to map out and understand these material flows, we also identified a number of hotspots (or problem areas) and opportunities, which are highlighted in this section.

Finally, we did a quick economic assessment on the material flows that are currently going to landfill. We looked at two basic scenarios: waste incineration with energy recovery and simple recycling material value. For each scenario we looked at the revenue and jobs potential of diverting this waste from landfill.

It is important to note that these options are not yet "circularity strategies", as these only look at the residual market value of the materials themselves. A circular strategy would involve examining the full value chain (e.g. materials should be designed for recovery when they are first produced) and the structural prerequisites required for circularity. Truly circular options offer the possibility of recovering far more value than simply looking at the market value of residual waste streams. Additionally, this is not yet an assessment of profit potential, as we only look at the lost revenue potential heading to landfill (and not the costs). These issues are covered in the following chapters on strategies and specific business cases.

EXPLORING THE CONTEXT

How the waste system functions in Charlotte

For a typical household, involvement in Charlotte's waste system includes weekly curbside pickup of municipal solid waste, biweekly pickup of recyclables, and occasional trips to drop-off centers or other locations to bring types of waste not collected at home. The costs of the program are covered by property tax fees paid to both the city and the county ($63 dollars in total) as well as other sources, such as special waste fees (for tires, white goods, etc) and the sale of recyclables. These costs are not differentiated by household size, the amount of waste (or recyclables), or income.

In the curbside recycling program, the city collects paper and cardboard (including paper cans and pizza boxes), plastics #1-5 and #7, milk and juice cartons and boxes, aluminum and aerosol cans, and glass bottles and jars in a single container. This system has been in place since 2010; before this, households had to separate paper products from other recyclables. While the new system solves logistical challenges (for example, fewer trucks are required), it also translates to a higher level of contamination and lower-quality recyclables.

Overall, recycling participation rates are low in Charlotte (53%), which is lower than other parts of Mecklenburg County (Mecklenburg County Residential Recycling Behavior 2009 Observation Study, 2009). Since 2009, in the state of North Carolina it has been technically illegal to landfill HDPE and PET (Granger, 2009), though there are no frameworks in place to prevent households from placing these materials in the municipal solid waste bins, resulting in a large share of these materials ending up in the landfill anyway.

If households would like to recycle batteries, light bulbs, textiles, hazardous waste, construction materials, electronics/appliances, oils, or tires, plastic bags, or other metals (like wire hangers, pots and pans), these must be taken to retailers or the county-operated drop-off centers in Charlotte. While the drop-off centers were originally established with the main purpose of collection of household recyclables, the majority of the waste by mass brought to the facility is bulky and construction waste from contractors and cardboard (which can be recycled in curbside programs).

Weekly use across all self-service drop-off centers was estimated to be roughly 800 visitors, of which 88% were households. This means that only 0.2% of the County's households are using the centers each week. For the roughly 19,000 households in Charlotte without a car (Governing the States and Localities, 2016), making a special trip to a drop-off center is practically infeasible, while it is also inconvenient for those with a car. Just the same, drop-off centers have been overcrowded, often with lines. This is due to the fast population growth of Charlotte (+30% over the past decade), resulting in too little capacity in peak hours (DSM Environmental Services Inc., 2017)

The city and county have no means for taking and recycling #6 plastics (including styrofoam), plastic dinnerware/cutlery, aluminum or plastic foils and wraps, non packaging glass (glassware, plate glass), diapers, or ceramics. Therefore, these materials are added to the residual waste bins.

For the majority of companies and other organizations located in Charlotte, the city and county does not provide waste collection and handling services. These organizations must handle waste themselves (for example contractors taking waste directly to landfills or drop-off centers) or establish a contract with a waste hauler. Larger haulers operate their own material recovery facilities for recycled materials or have partnerships with recyclers, making it cheaper to process recycling than general solid waste (with high tipping fees for landfilling). This provides a good incentive for companies and waste haulers to strive for more ambitious recycling rates.

Mecklenburg County is responsible for operating the material recovery facility (MRF) where household recyclables end up. At this facility, recyclables are separated and baled and sold on to third parties. Lately, with the Chinese ban on imports of recyclables of a low quality, finding an appropriate market for these materials has become more challenging, resulting in an accumulation of recyclables.

Charlotte has a large number of recyclers operating in the region, processing everything from plastics to electronics, though much of the material these companies are processing is post-industrial or imported waste rather than regional post-consumer waste. The main reason for this is that regional post-consumer waste is largely too contaminated, with impurities and other materials mixed into the loads.

With export markets disrupted by the Chinese ban, there may be further incentive now to upgrade the quality of recyclable materials locally (for example through washing and shredding), which could benefit local recyclers and increase employment in the local recycling sector. In North Carolina, it has been shown that increased recyling leads to far more jobs created than lost in industries such as timber harvesting and waste disposal (Institute for Local Self-Reliance, 2002).

Current initiatives in Charlotte

Though there is a new wave of momentum behind the circular economy, there are already many initiatives in Charlotte that can already be described as circular.

For example, the city established the Healthy Communities program to divert waste from landfill and increase composting and recycling by educating locals. In 2016, around 6,600 citizens were reached through events to provide information on waste separation. In 2017, the city won the Excellence Award for Innovation in Communication, Education and Marketing for the program from the Solid Waste Association of North America. Solid Waste Services is planning on continuing this program to reach more households over the coming years.

As Charlotte strives to become a zero-waste city, there will still be a number of landfills in the region that will need to be remediated. In Mecklenburg County alone, there are eight heavily-polluted landfills that were put into place when environmental regulations were less stringent. There is already precedent in Charlotte for how to make use of these landfills. The Double Oaks landfill was cleaned up with an investment of $2.1 million and is now a play area and park. In 2016, Charlotte approved a plan to convert another old, polluted landfill site into a solar farm to produce 2-3 MW of electricity (Henderson, 2017).

In addition to these city-level programs and projects, there are a number of entrepreneurs working on interesting initiatives. A few examples, include:

Crown Town Compost - Not everyone in Charlotte has the opportunity for at-home composting and although there were collection programs for yard waste, there was no program to handle the food waste going to landfill from households. Crown Town Compost was established to collect food waste from households and restaurants in a weekly collection program. While this food waste is currently composted with Earth Farm Organics, Crown Town is looking for alternative ways to handle food waste as the program scales up further.

Habitat for Humanity ReStores - Habitat for Humanity is a charity organization that mobilizes volunteers and funding to build houses for families with low incomes who otherwise could not afford to own their own homes. The ReStores are thrift stores for secondhand building and household materials (such as lighting fixtures, cabinetry, furniture, wood, etc). The ReStores divert waste from landfill as well as providing income to fund the Habitat for Humanity program.

Goodwill's Opportunity Campus - A new project established to provide a learning center for teaching people who struggle to find work new skills to get them into the workforce. In addition to the educational programs and two thrift stores on site, the campus also includes a garden for food production. The food is served in the cafe on-site, which also serves to teach people new cooking skills.

100 Gardens - An educational program that aims to teach students about science, technology, business, marketing, and much more through operating aquaponics labs (hydroponic greenhouse production combined with fish production in a symbiotic system). So far, ten labs have been established in Charlotte schools to provide students with a hands-on way of learning about how natural systems function, while also inspiring kids to learn about technology and applied sciences.

How the waste system looks spatially

Charlotte has some areas of the city with extreme poverty and high unemployment rates of up to 50%. We wanted to see if waste collection or processing areas correlated with these areas of economic strife. The southern part of the city, forming a wedge that starts at the center, has a significantly higher median income than the rest of the city. This whole area also only has one recycling center placed on its far southern part and no landfill. At the same time, the lower income areas in the Northern part of the city center have several recycling centers.

This distribution has of course happened organically as the city has developed, but at this point it may form a logistical challenge that makes it more costly to increase the separation capacity because more trucks will have go back and forth to this wealthier area. For residents in the wealthier areas it may be more cumbersome to visit recycling centers, while residents in low-income areas may experience the noise and air pollution of recycling centers, landfills, or trucks traveling to these as a nuisance in their neighborhood.

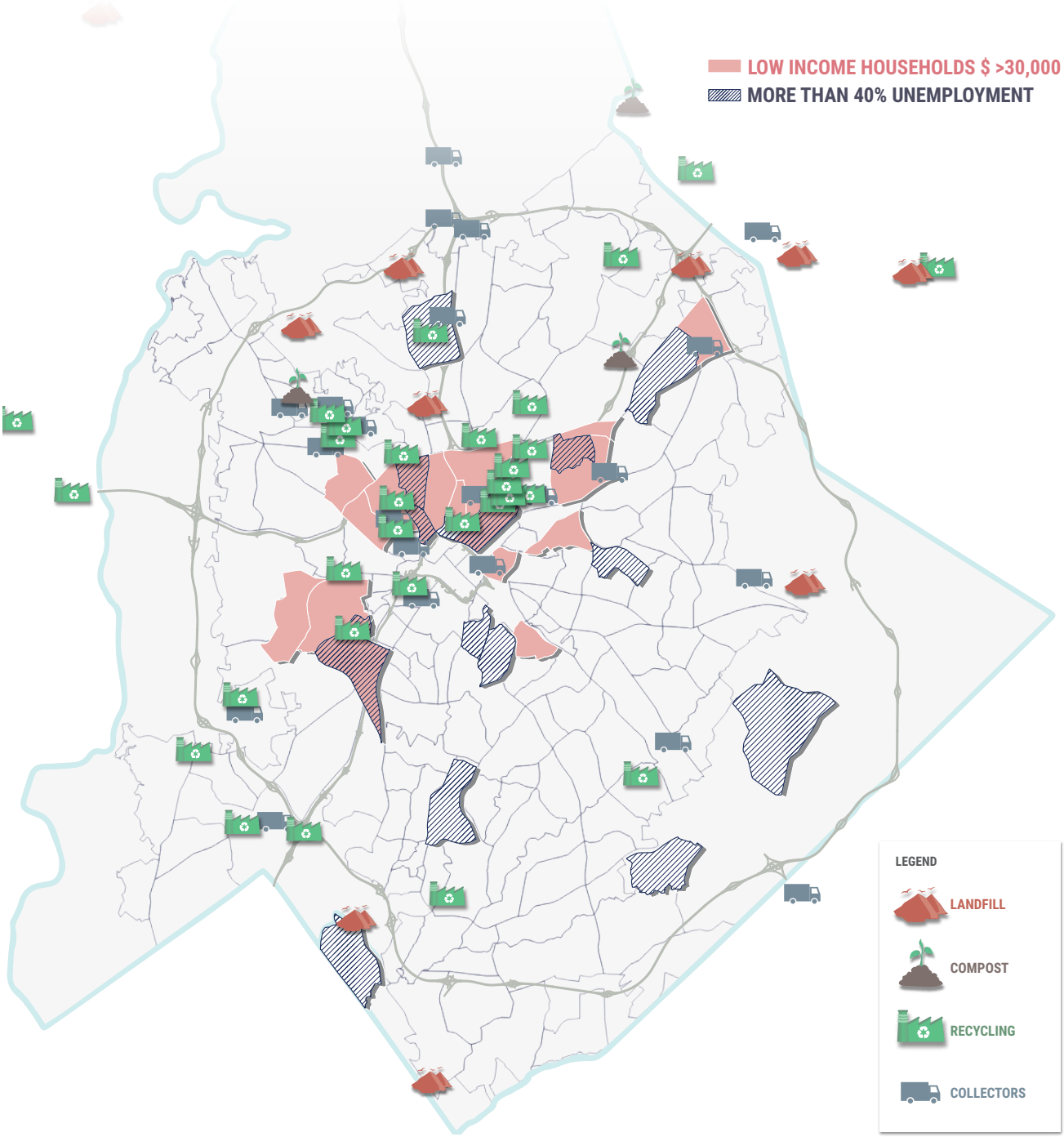


Figure 5. Spatial Aspects of Charlotte's Waste System and Neighborhood Economic Indicators

MAPPING THE STAKEHOLDERS

In Charlotte there are a large number of stakeholders involved in the waste system, including the waste generators (which involves more than 300,000 households and over 60,000 companies and other organizations), waste haulers focused on different client groups, more than fifty waste processors working with specific waste streams, stakeholders that store waste in landfills, companies that use or could use recycled materials, and overarching stakeholders such as the city and county.

The large number of influential and affected stakeholders is one of the main challenges the city faces in achieving circularity. As there is no one party with central oversight over the entire waste system in Charlotte, it makes it difficult to sketch a complete picture. The city and the county have access to the most complete data on households and small businesses, but as they are responsible for different parts of the waste system, both have gaps in their knowledge. Additionally, data is missing for a large share of the waste system in Charlotte as it bypasses both the city and the county when it goes from private companies to private haulers and processors.

Figure 6 shows the material flows between different stakeholder groups in Charlotte. Thicker lines represent the wastel flows for which the city or county have information, while the other lines are where there is a lack of central oversight on what is happening in the waste system.

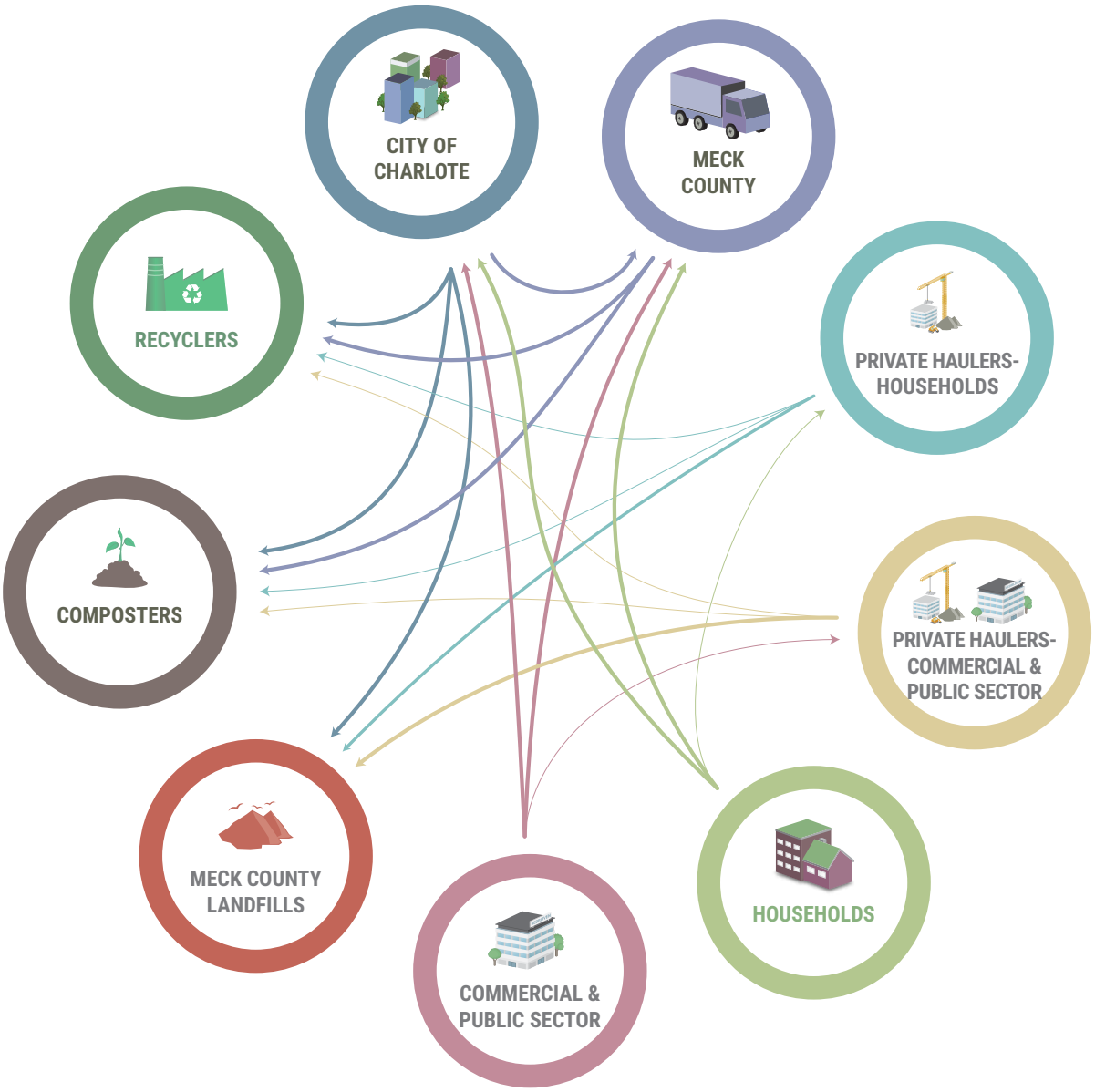
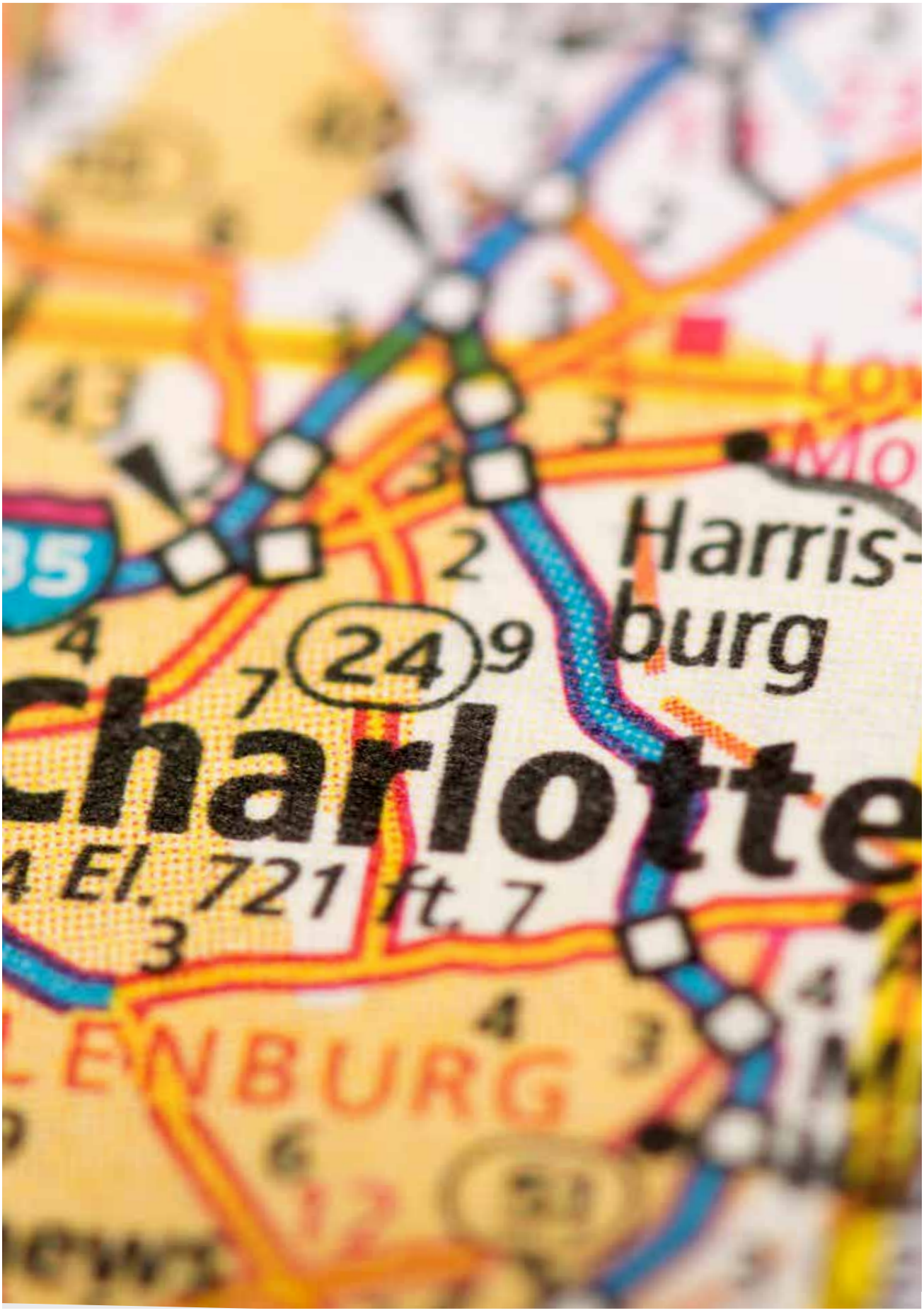


Figure 6. Material Flows between Charlotte Stakeholders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Beyond material and information flows between stakeholders in Charlotte, there are important financial flows to consider, including tipping fees, disposal taxes, special taxes (such as tire taxes or white goods taxes), revenues from recyclables, commercial service costs, etc. The structure of these financial flows is key, as it will determine which stakeholders support or are opposed to certain circularity measures.

For example, the owner of a landfill would presumably be opposed to any measure which reduce the waste to landfill without also resulting in a commensurate benefit in some other way. In this way, we need to take the position and desires of influential stakeholders into account to ensure strategies are feasible. In addition to direct opposition or support of specific measures, stakeholders may see circularity strategies as a way to position themselves in a competitive market. Waste haulers, for example, who compete for contracts, have a strong incentive to support measures which help their position.

One of the most complicated challenges around aligning interests and finding a strategy that works for all is the dynamic between the city and the county. Waste and recycling from households and some small businesses is collected by the City of Charlotte. However, due to a solid waste interlocal agreement with Mecklenburg County (currently in place until 2028), the county is responsible for this waste from this point on.

Outside of the direct financial flows between stakeholders, there are indirect economic issues which affect stakeholders in the region. For the areas in Charlotte where poverty is a major struggle, ensuring that a shift to circularity can provide a means for reducing poverty through workforce development and job opportunities is a prerequisite for adoption. At the same time, the means for achieving circularity should fit within the cultural and social structure of different communities and address additional challenges they face.

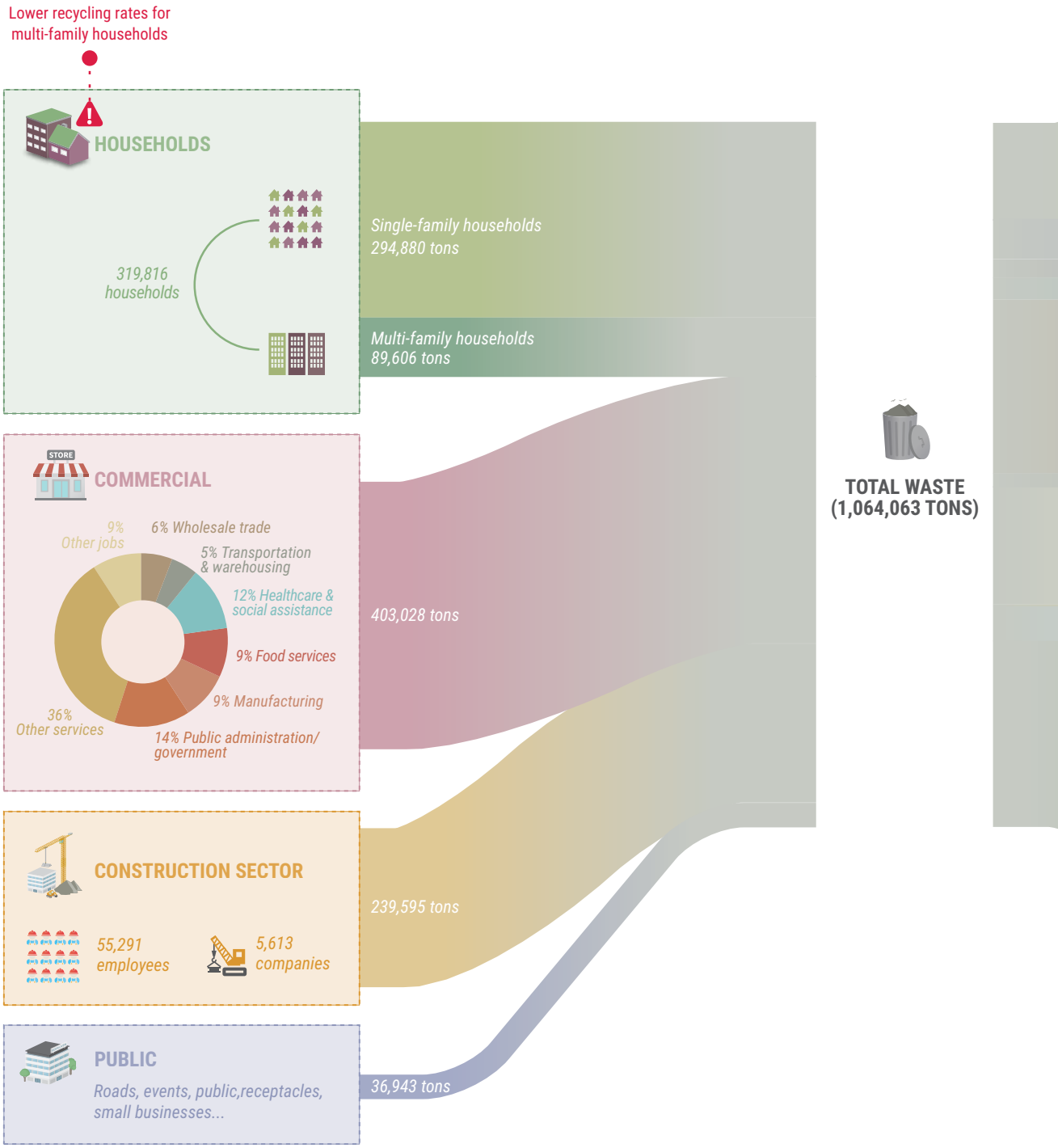
Finally, activities of other stakeholders (for example in the market or in policy) outside of the scope of Charlotte can have a large impact on how the waste system of the city functions. One example is China's decision to limit the import of recyclables to those of a high quality, due to environmental and health reasons. In particular, household plastic wastes, unsorted paper, and some textile wastes will no longer be accepted (Prisco, 2017), which poses a challenge as China is the main importer of plastic wastes (Velis, 2014).

Chinese policy on materials accepted and the quality of recyclates will have a large impact on global markets for recyclables and is expected to have a large negative impact on United States recycling businesses, threatening thousands of jobs (Rosengren, 2017). In some cities in the United States, this ban has already resulted in the refusal of certain types of plastics (van Fleet, 2017). The effect of China as an external stakeholder could affect the feasibility of recycling options, provide an incentive to reduce plastic waste production, or present a barrier for preventing plastic wastes to landfill.

UNDERSTANDING WHAT HAPPENS WITH WASTE IN CHARLOTTE

Based on the data available (mainly from households and small businesses), we put together the big picture of waste flows in Charlotte, looking at where waste is coming from, what the composition of that waste is, and where it is ending up. Overall, we see on the left side that the amount of wastes coming from the commercial sector and households is roughly equal, with construction and demolition (C&D) wastes also contributing a large share. C&D wastes and organic wastes dominate the total mass of waste flows in Charlotte (showed in the center of the graphic), followed by paper and plastics. On the right side of the graphic, the linear nature of the waste system in Charlotte is evident through the large share of wastes that end up in the landfill compared to what is recycled.

In the graphic we have highlighted a few important issues and opportunities for the waste system of Charlotte. One of these issues is the low recyclable collection rate in Charlotte, which is particularly low among multi-family households.



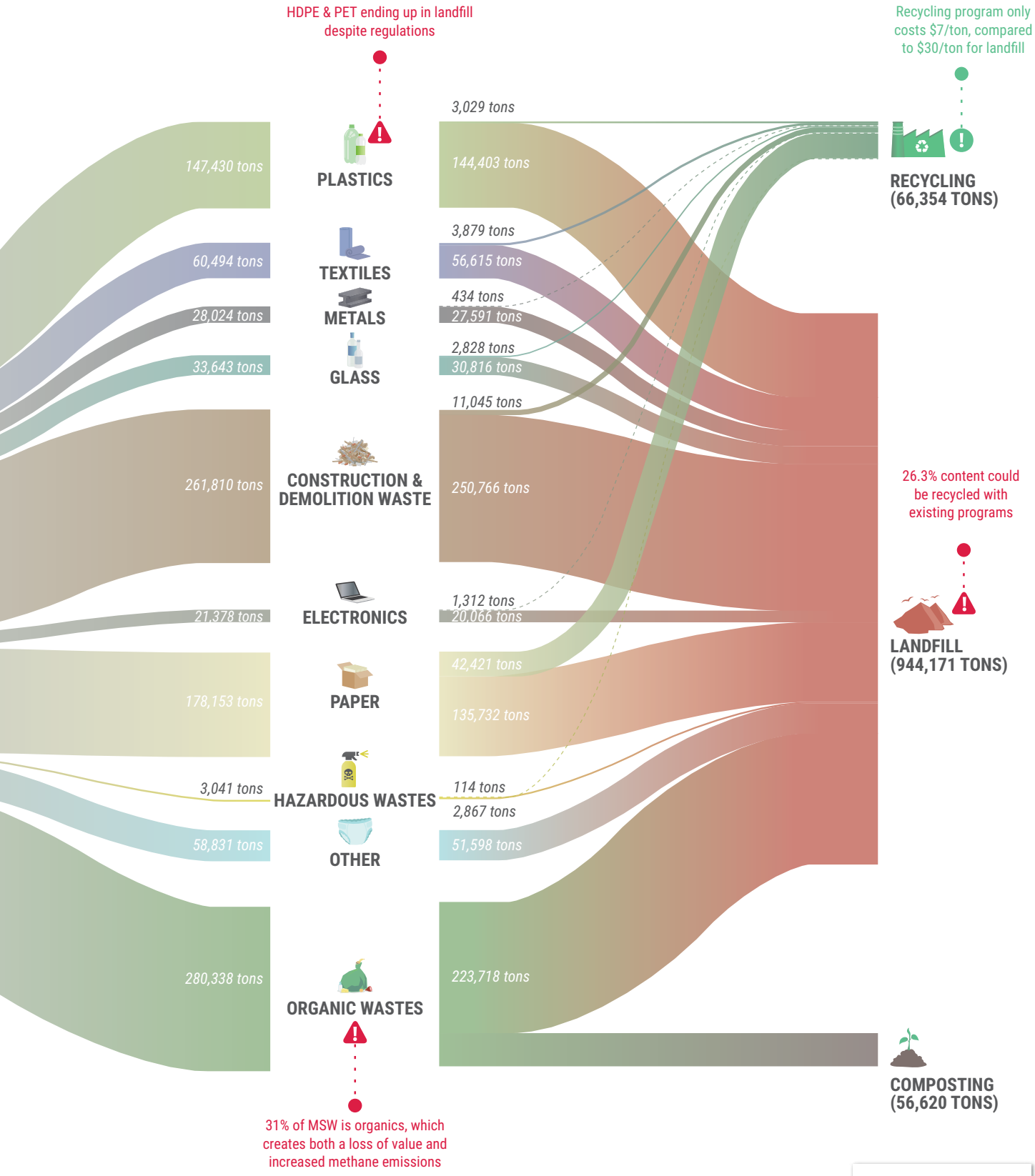


Figure 7. Charlotte Waste Material Flows

Landfilling materials in Charlotte comes at a greater cost than recycling - $30/ton versus $7/ton

Sending materials to landfill in Charlotte comes at a greater cost than recycling ($30/ton versus $7/ton). This means that even before new circularity strategies are explored, there may be a business case just for expansion of existing recycling programs and increasing recycling participation rates. If around 10% of the materials heading to landfill were recycled instead, this would result in more than $2 million in savings.

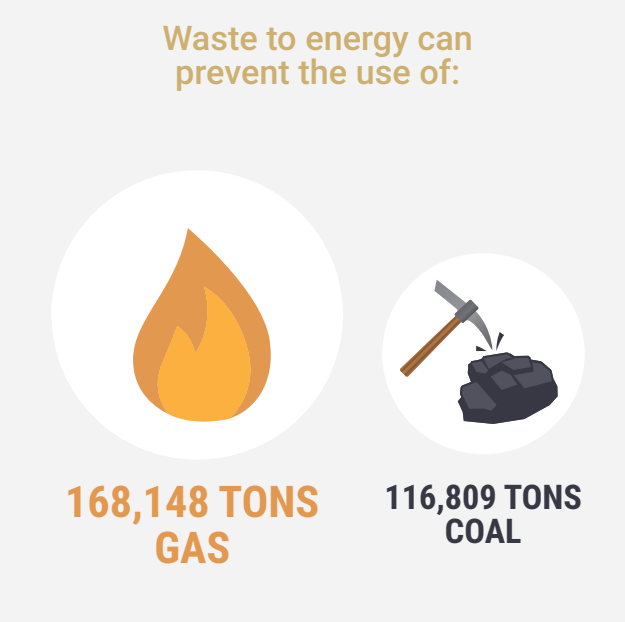
In addition to economic losses, landfilling materials is also associated with environmental impacts. Envision Charlotte is working to establish a low-carbon strategy, which means striving for a net annual CO_2e emission of less than two tons per person. Reducing the total waste to landfill is one way of reducing emissions. Conventional landfilling of municipal solid wastes contributes between 138-601 lbs CO_2e per ton (Manfredi et al., 2009). In total, between 0.08 - 0.34 tons of CO_2e per person can be reduced by shifting to a completely zero-waste system.

Nearly a third of the total mass of materials going to landfill is organic waste. In addition to creating a loss in value and increasing the land requirements for waste storage, organic wastes in landfill produces a large amount of methane emissions during decomposition, which is a greenhouse gas around 25 times stronger than CO_2.

An additional issue is that landfilling wastes increases the demand for virgin resources, and can exacerbate impacts upstream associated with material extraction. Recycling materials such as plastic and paper can prevent the need for new production of these materials, while even waste incineration can reduce the need for fossil fuels such as natural gas or coal in electricity production.

As an example, you can consider wood and paper production, which has a large land footprint. To produce the wood and paper that is currently landfilled in Charlotte, you would need an area of nearly 17 square miles. To put this in perspective, you can consider that this is around 5.6% of the area of Charlotte or more than 100 times the area of the city's Freedom Park. A large share of this land area could be avoided by recycling paper and wood rather than sending it to landfill.

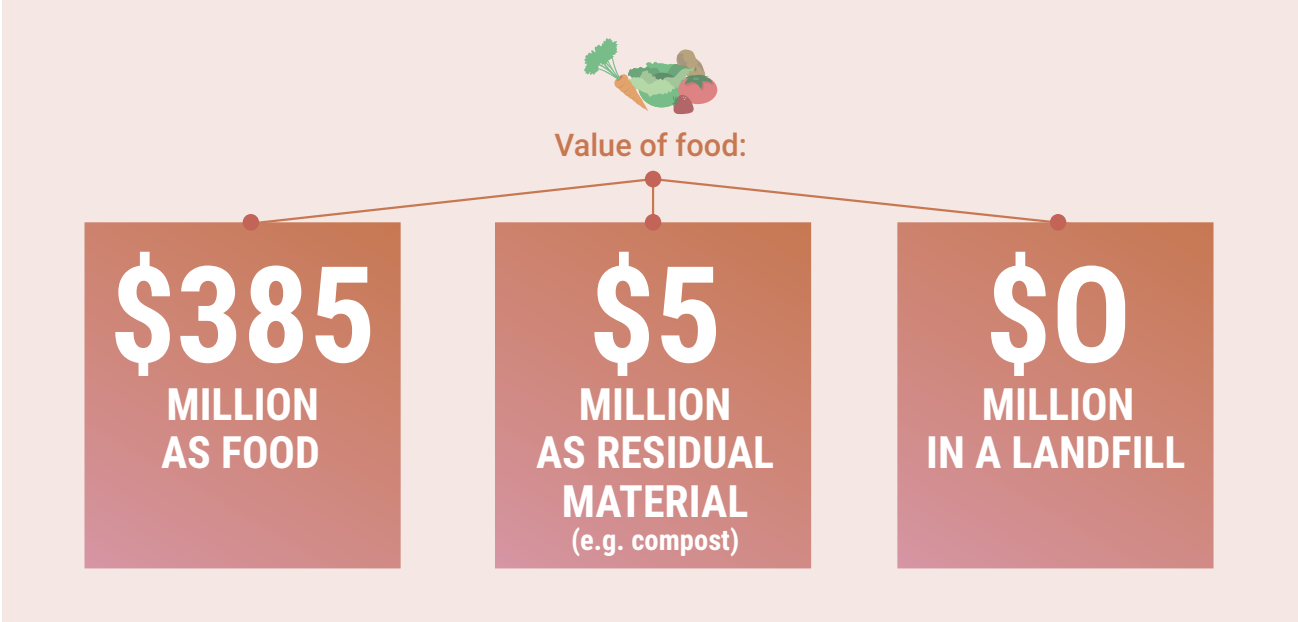
Waste diversion in Charlotte can prevent the need for additional virgin material consumption



The land required for the production of wood & paper landfilled in Charlotte is 16.74 mi²/year, which can be avoided with effective recycling

+

In Charlotte, nearly 18% of food ends up in the landfill. This food could feed 149,487 people for a year.

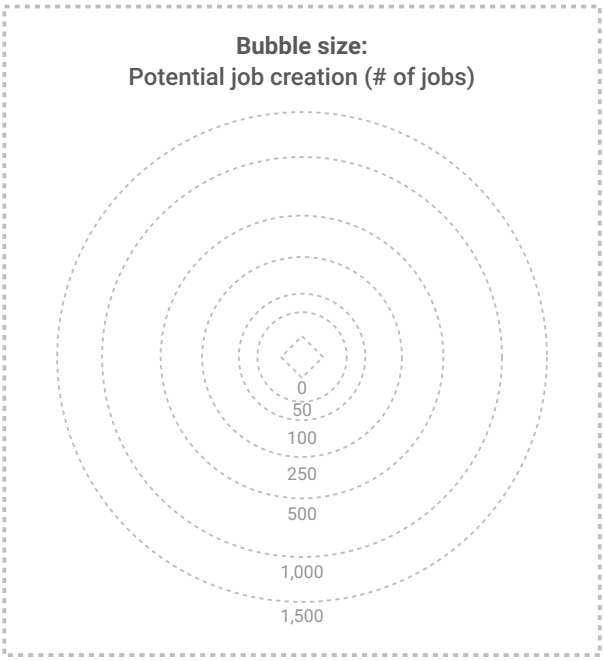


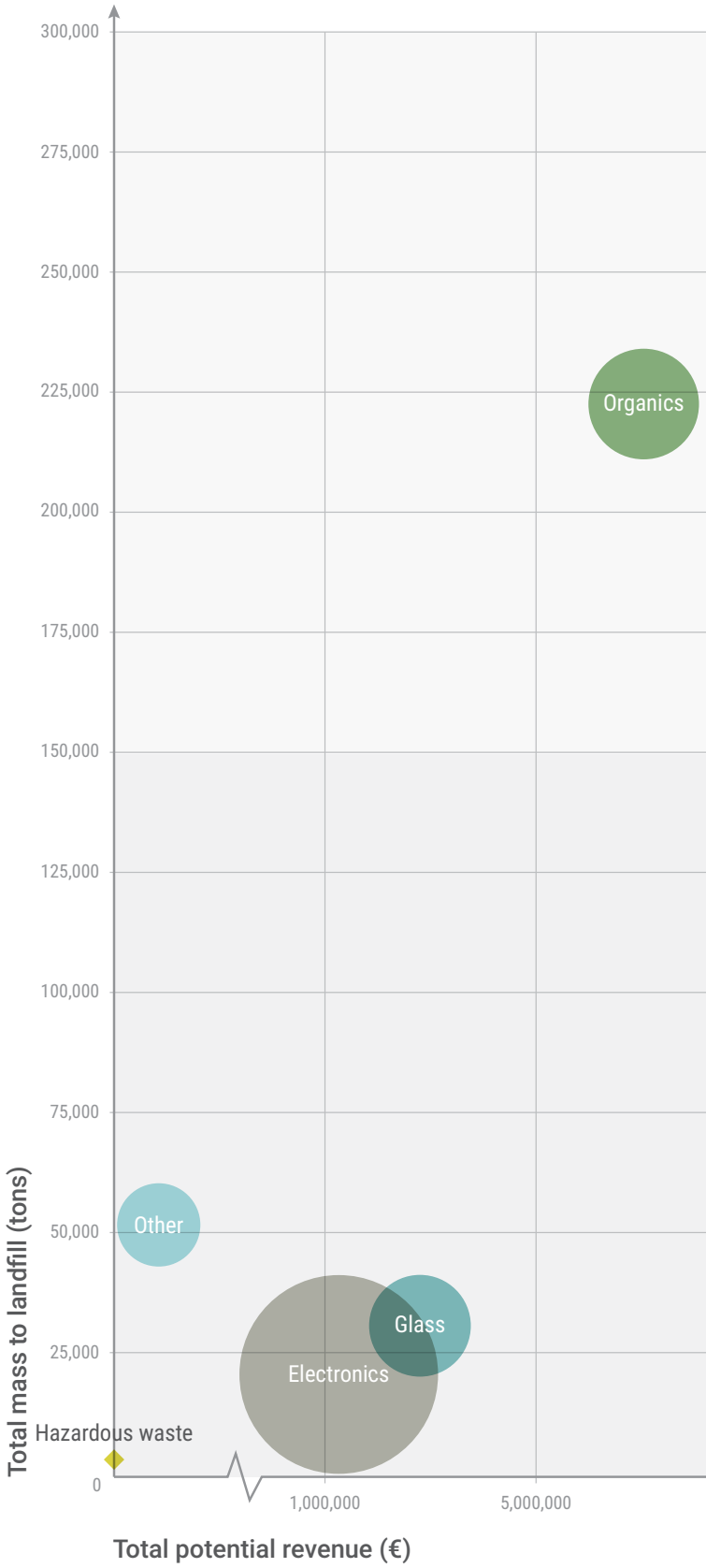
UNCOVERING THE POTENTIAL OF CIRCULARITY

Circularity is not only about increasing recycling rates, but integrating circularity across the entire value chain and economy. The highest-impact strategies reduce the amount of material throughput and waste entirely.

As one example, consider food waste. In Charlotte, around $385 million worth of food ends up in landfill, which would have the highest value if it were simply consumed as food. If this food waste was instead diverted to compost, it could be worth up to $5 million, which is far better than its cost to landfill, but still results in an economic loss of $380 million in total for Charlotte.

When designing a circular strategy, you should consider measures which make the highest-value use of material wastes possible. Mixed food wastes are of relatively low value, but with the right strategies in place, different fractions of that food waste, such as coffee grounds or fruit peels, could be applied to the production of higher-value products. However, this also requires re-imagining the waste system to enable separate collection or post-collection sorting. Mixed or contaminated material streams will be less economically viable to work with. Understanding these types of tradeoffs requires a much deeper assessment.





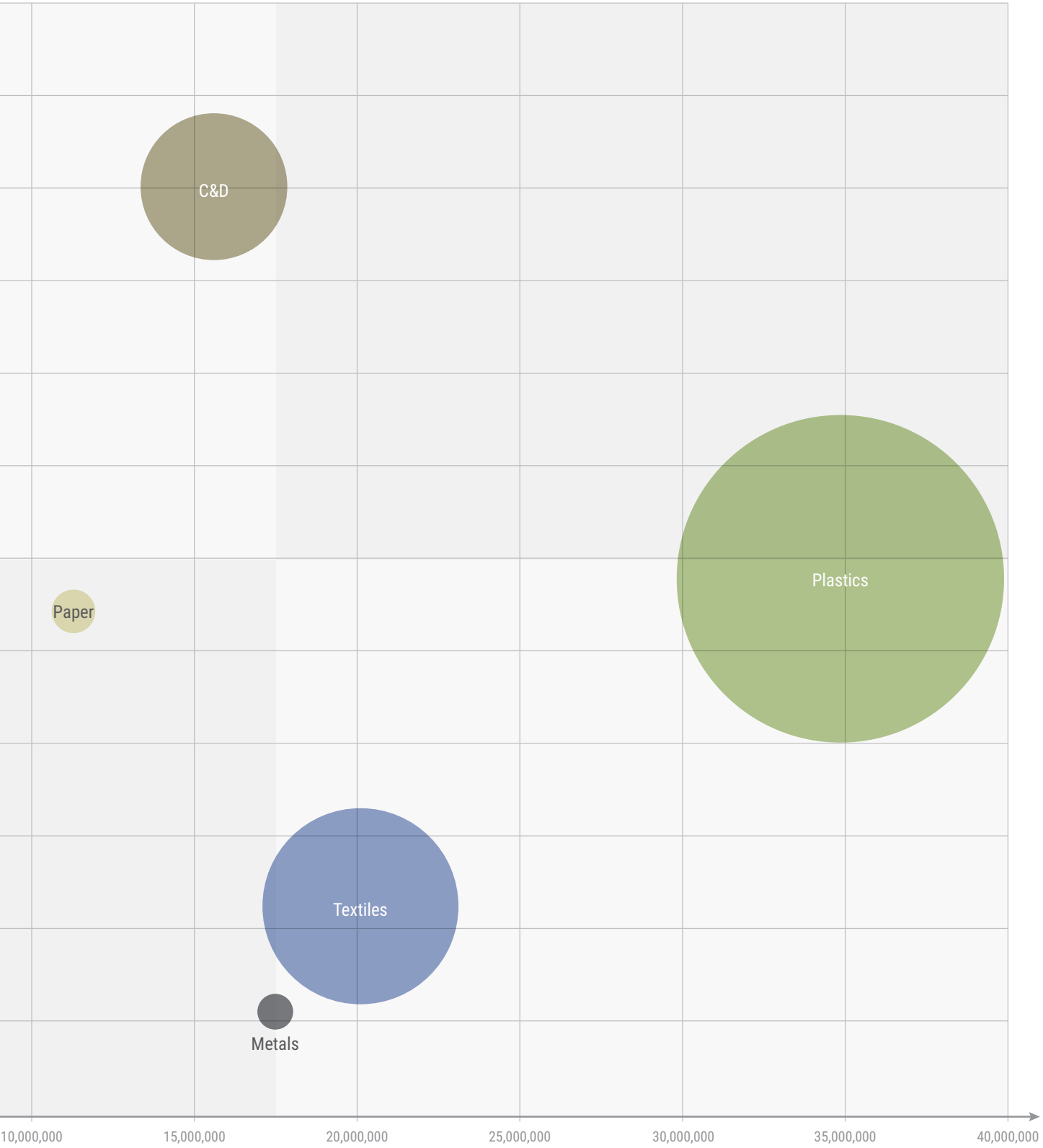


Figure 8. Revenues and Job Potential from Residual Value of Materials Landfilled in Charlotte

Without yet going to this level of detail, we took a first quick look into the potential value of the wastes going to landfill in Charlotte. We evaluated a rough economic potential for the materials, looking only at the residual market value of wastes (e.g. baled PET or waste pallets) and rough number of jobs created by recycling different materials. Figure 8 shows the total mass (y-axis) and total revenue potential (x-axis) as well as the estimated jobs potential (size of bubbles) for different aggregate materials categories. Materials such as plastics have such a high volume that the total potential revenues and job creation from this material stream is much higher in total than that of something like metals or electronics, which have a higher marginal value.

Just based on residual value and potential for job creation alone, the plastics going to landfill is the single most promising waste stream to start with. A total of more than 144,000 tons of plastics end up in Charlotte's landfills. Recycling these materials could create more than 1,000 jobs, bring in $35 million in revenues, and avoid the consumption of nearly a million barrels of oil a year by avoiding virgin material consumption.

As a comparison, we also consider a scenario for waste incineration with energy recovery. While this would not be recommended as a circular strategy, it has some benefits over landfill, including eliminating the land footprint of waste storage, and generating revenue from energy production. Waste incineration-to-energy has been widely adopted across Europe as an alternative to landfill. However, many countries that have adopted waste incineration are now locked into costly investments in waste incineration technologies and unable to shift towards higher-value recycling strategies in the short term, even when the potential benefits are clear.

Charlotte has an opportunity for leapfrogging to more truly circular options, but for some wastes where markets do not exist for reuse or recycling it may be more economically viable to explore medium-term options for energy conversion, even on a small scale, for example through biogas production.

As expected, the potential revenues and job creation are much higher for the residual material recovery than for energy production when we compare the scenarios side-by-side. What this does not take into account, however, is the costs of not only investing in logistics and infrastructure (which is trickier with recycling than incineration), but also the social, political, and economic systemic changes that need to take place in society as a whole. In the next chapter we explore how to develop a strategy for a zero-waste Charlotte in more detail, but a large part of the realization of circularity will require not only strong business models, but also paradigm shifts in our way of thinking about supply chains.

Diverting wastes from landfill in Charlotte can result in a comparable amount of additional revenues to those generated by the mining, oil, and gas sector

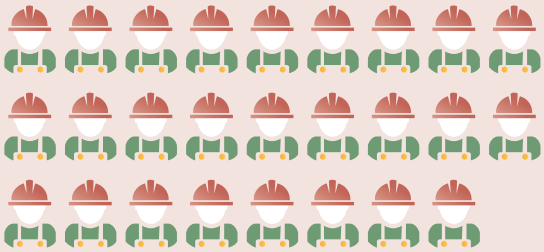
Circular economy strategies such as recovery of components, refurbishment, or leasing can create even more jobs

Decreasing the wastes going to landfill in Charlotte would result in additional jobs

Waste to energy

UP TO 102 JOBS

Recycling



UP TO 2,647 JOBS

Circular economy strategies such as recovery of components, refurbishment, or leasing can create even more jobs

If all plastics landfilled in Charlotte were recycled instead, this would save 936,329 barrels of oil per year while creating jobs and revenue

144,403 TONS
PLASTICS LANDFILLED

or

936,329
BARRELS OF OIL AVOIDED

+

35 MILLION
REVENUES POSSIBLE

+

1,343
JOBS CREATED

TOWARDS A CIRCULAR CHARLOTTE

DEVELOPING A STRATEGY FOR A CIRCULAR CHARLOTTE

The magnitude of the transformation that has to happen in Charlotte to achieve the circularity goals outlined in Chapter 2 will require a coordinated set of actions over a number of years, supported by strong leadership from local government, the private sector, and civil society. In this chapter, we synthesize the results of our stakeholder workshops, interviews, and research into a recommended plan of action for Charlotte to move towards a circular economy.

We first consider some of the barriers that Charlotte faces on its circular development path. Secondly, we delve into the systemic changes that need to take place to tackle these barriers and take advantage of the opportunities. We then present a draft roadmap of actions that need to be taken over the short, medium, and long-term. Some of these actions require physical changes to Charlotte's infrastructure, some require technical innovation, while others require social mobilization. Above all, success will require the city committing to a long-term transformation trajectory with sufficient financial and human resources dedicated to the process. An essential component of this process will be the development of buy-in from the city's residents through a communications campaign and a city-wide rebranding as Circular Charlotte. The commitment to a circular economy should become a source of pride and local identity for the city and its residents.

As we describe here, there is also an overarching need for Charlotte to maintain accountability for its progress and for achieving the goals it sets. To underpin the other actions presented in this report, it is essential to develop a data collection and monitoring program that details how the city is progressing on improved resource management and inclusive economic development.

The strategy presented here is an initial recommendation that will need further revision and vetting. As more information is uncovered and specific circular business cases for the city are defined, detailed action plans will need to be drafted each year. As such, the strategy here should not be seen as a static document, but rather as a seed from which more concrete action pathways will sprout and be further defined.

OVERCOMING BARRIERS TO ACHIEVING CIRCULARITY

If done right, a circular economy in Charlotte will create opportunities for local employment, reduce the socio-economic divide in the city, and establish new industries that lead to greater local resilience and reduced environmental impacts. Ideally no waste will be going to landfill and all materials flowing through the city will be used as the basis for new circular manufacturing.

Many changes will need to take place within the city to make this possible and initial investments will be needed to unlock the value of circular business opportunities further down the line. As we've described in Chapter 3, around 88% of the waste collected from residents and small businesses in Charlotte is currently ending up in the landfill. The remaining recyclable material that is collected separately, as a single mixed stream, is sorted and baled at the local Materials Recovery Facility (MRF), which is operated by Mecklenburg County.

Up to 15% of the material sorted at the MRF still ends up in the landfill because it was incorrectly identified as recyclable or could not be properly sorted with the automated equipment at the MRF. The decisions that citizens make about what to put into the recycling system have a significant impact on how well these materials can be processed and the quality of the recyclables that are ultimately harvested. Leaving recyclables out in the rain, for example, can result in paper sticking to the plastic and glass, drastically reducing the ability of the automated sorting systems to separate these materials. And though plastic bags were once accepted for recycling in Charlotte, this has not been the case for many years. Putting plastic bags in the recycling, or even throwing out recyclables in a plastic bag, clogs up the sorting machines at the MRF, grinding the whole process to a halt several times a day.

Once the materials are finally sorted and baled at the MRF, they are sold off on the second-hand materials market. Some of these may stay in the Charlotte area, but most (especially prior to the Chinese ban on low-quality recyclables) leave the area. Even when this system is working perfectly, just selling these materials at scrap prices is a missed opportunity. The value of the bales of materials could be much greater - if more local businesses were geared to use them as resource inputs. With good design and effective technology, these base materials can be transformed into products worth hundreds or thousands of times the cost of the original scrap.

Clearly, however, there are a number of challenges to resolve before circular value chains can take root in Charlotte. In shaping a strategy, it is important to have an understanding of both the real and perceived barriers standing in the way of circularity. Once these are mapped out, they can be systematically addressed through a strategic plan. Below we describe some of the most significant barriers that have emerged throughout our research and in our conversations with stakeholders, grouped across four categories.

Physical and Technological

Though technological advancement is generally far ahead of what is commonly implemented, there are still some gaps in the physical and technological infrastructure that we need for a transition to a circular economy. Collection from multi-family housing remains a challenge. Where over 50% of single family homes participate in recycling, that proportion drops to only 15% of families living in apartment blocks. This is due to a variety of factors such as lack of space for storing separate recyclables, lack of service providers to do in-house collection, and the anonymity of individuals (making it difficult to enforce recycling behavior in line with regulations).

There is also lack of infrastructure in the city more broadly. For instance, Charlotte currently has no means for recycling styrofoam, plastic dinnerware and cutlery, aluminum or plastic foils and wraps, diapers, ceramics, and any glass that is not used in packaging (glassware, plate glass). Additional facilities, such as centralized plastic shredding equipment, have been cited by Engineered Recycling Company, LLC as potentially important pieces of equipment that could allow more smaller recyclers to afford to start businesses in the sector.

Finally, there are some more systemic challenges in this category: perhaps most importantly, the majority of products on the market are not designed for high-value reuse and recycling. They are often made of mixed materials, have unknown additives, are assembled with glues making them difficult to take apart, or use problematic dyes and colorants that can contaminate whole recycling streams. Now that most cities collect mixed stream recyclates, it is also essential to further develop sorting technology using more advanced optical techniques or robotics.

Social and Cultural:

One of the more fundamental challenges that all societal transitions face lies in changing the behavior and mindset of people. Participation in recycling programs is still far from 100%, particularly in multi-family households where physical challenges provide an additional barrier. Moreover, many people are still unaware of sustainability challenges, and therefore do not have as much personal motivation to consume responsibly. On the other side of the issue, the transition to a circular economy will require a great deal of new skills and knowledge: a whole new workforce of people trained to remanufacture products and reuse materials in different ways. To make this transition work, companies from across the value chain will need to collaborate - out of their own intrinsic motivation for change, or through incentives to do so.

Economic and Financial:

In any kind of transition, you need to invest resources to develop new knowledge, technology, and ways of doing things. The financial piece of change management can sometimes be challenging. Currently, most recyclables have low value - partly, in many cases, because of high levels of contamination and lack of purity among the collected resource streams. A bale of pure PET bottles has much higher value than a bale of mixed plastic, for instance. It is essential to work actively with the market to develop solid business cases for circular resource management (some examples of which can be found in the next chapter of this report). There is also the usual challenge of securing money for capital investment: small recyclers often cannot afford the expensive equipment that is needed to get a recycling business started.

More generally, the transition to a circular economy can be hampered by the fact that most environmental impacts (externalities) are not currently priced within day-to-day transactions, there are not sufficient funding vehicles available for projects focused on high social and environmental benefits, and that financial partners tend to be risk averse.

Political and Legal:

There are, finally, a number of political and legal barriers. One of these is the solid waste interlocal agreement between Charlotte and Mecklenburg County, which currently dictates how all of Charlotte's waste is handled after collection (further described on page 43). In general, the process of passing new laws is very slow and frequently involves state involvement, so it can be challenging to get new regulations in place that could advance the circular economy. Aside from this, there is a general aversion to, for example, any kind of taxation, which could be an important policy instrument in pushing for more sustainable material use in products.

On the day-to-day level, existing rules and regulations can hamper how certain waste streams are used and where certain activities (such as food production) can take place. These rules often exist for good reasons, but with changes in technology they become outdated and should be revised. There is also, however, legitimate concern about the health and safety of reusing certain post-consumer materials, which could lead to lawsuits (the fear of which can keep entrepreneurs from entering certain sectors).

KEY BARRIERS TO CIRCULARITY IDENTIFIED IN STAKEHOLDER SESSIONS

Physical and Technological

- Collection from multi-family housing
- Space requirements
- Sorting capabilities - technology still needs to advance
- Health and safety of recycled materials
- Mixed materials in products: lack of design for reuse/disassembly/recycling
- Lack of infrastructure for collection and processing

Social and Cultural

- Lack of participation from residents
- Lack of training and knowledge
- Consumption patterns
- Lack of capacity and workforce
- Lack of recognition for stakeholders who contribute to solutions
- Difficulty establishing partnerships and getting supply chain parties to cooperate

Economic and Financial

- Low value of recyclables - finding proven circular business cases that work
- High cost of some equipment - small recyclers can't afford capital investment
- Misalignment of financial incentive structures (no pricing of externalities)
- Lack of appropriate funding vehicles
- Risk aversion of financial partners (i.e., banks)

Political and Legal

- Solid waste interlocal agreement between Charlotte and Mecklenburg County
- Resistance to new legislation / taxation
- Difficulty in passing any local laws without state involvement
- State and national political climate opposed to innovation on sustainability
- Health and safety of recycled materials (contamination)
- Fear of lawsuits and actual risk of lawsuits (i.e., compost quality)
- Land use and zoning regulations (i.e., with food production)
- Regulations on how waste can be used
- Labeling reform (for food, recyclable materials, etc.)

SYSTEMS CHANGE FOR CIRCULARITY

In this section, we describe some of the actions we believe are necessary for Charlotte to take strides towards circularity in the near-term, mid-term, and long-term (also summarized in the roadmap on pages 66 - 71). As with the vision and KPIs, the actions in the roadmap have been drafted with input from stakeholders across Charlotte. We recommend that this draft be used as the basis for a co-creation process to further refine these plans. Once the roadmap is finalized, it should ideally be revisited on an annual basis to make the activities for the upcoming year more specific and relate them to concrete yearly goals.

SHORT-TERM ACTIONS (0 - 5 YEARS)

Charlotte's transformation to a circular city clearly cannot take place overnight. Near term actions should focus on building awareness among the city's citizens, business owners, and other key stakeholders on what the circular economy is and the different opportunities it can provide as well as laying the groundwork for tackling some of the barriers described in the previous section. In addition, it is essential to identify tangible actions, showcases, and circular business cases that can be executed quickly in order to build support for the approach and demonstrate its value. Further steps should include capacity building and efforts geared at longer-term transformation, such as neighborhood action plans, the establishment of new partnerships and institutions, and monitoring programs to track the city's progress on circular economy metrics (i.e., the KPIs presented in Chapter 2).

Public Sector Commitment and Circular Strategy Development

The activities in this category establish the foundation for Charlotte's transition. As evidenced through this study, some of the first and most important steps are already underway: securing public sector commitment to the circular economy and getting a basic understanding of the opportunities within the city to progress in this direction.

- **Establish public sector commitment to the transition to a circular economy.** The city management should have a shared understanding of what the circular economy means and the opportunities it could bring to the city. There should be commitment to allocating resources (both time and money) to making the circular economy a reality in Charlotte.
- **Complete baseline assessment on Charlotte's current circularity performance**. City representatives should agree on the metrics used to evaluate Charlotte's circularity performance. A baseline calculation of how Charlotte is currently doing on these metrics should be completed and used to track later progress. A significant part of this baseline assessment has already been completed in this report.
- **Develop initial circularity strategy.** The circularity strategy presented in this report should be refined and vetted by the city management and other key stakeholders, ideally resulting in a more specific one-year action plan along with a timeline for reviewing and advancing the strategy on an annual basis.
- **Align Charlotte's other strategic goals with circularity.** To ensure alignment between Charlotte's circular economy strategy and other political goals, the city should conduct a review to see how other targets (liveability, economic development, climate change objectives, etc.) coincide with the circular economy plan. These should be cross-referenced and integrated for consistency.

Communications Strategy and Development of the Innovation Barn

Once there is clarity and alignment on the basic principles of the circular economy and Charlotte's approach to this transition, the next steps should focus on communicating this commitment to the local, national, and international audiences and developing some tangible showcases. An important part of this visibility is the development of Charlotte's first circular showcase, the Innovation Barn, which Envision Charlotte is already developing.

- **Rebranding the city as Circular Charlotte.** Going public with the city's commitment to the circular economy should ideally be coupled with a branding process identifying the city as Circular Charlotte. This should include a recognizable logo and color scheme that can be used to signpost any activities related to the transition plan.

- **Communications campaign for Circular Charlotte.** The city should develop a comprehensive communications strategy around the circular economy plan and its other sustainable development commitments. This communications strategy should include a publicity campaign, largely targeted at Charlotte's residents. It should build awareness of the plan and give citizens clear ways that they can get involved and participate.

- **Define plans for the Innovation Barn as the city's first Circular Living Lab**. Already underway, the city should define plans for the Innovation Barn, clearly identifying it as the city's first Circular Living Lab / experimental hub. The Barn should become the physical seat of circular activities in the city, encouraging participation and providing ways of engagement for all of Charlotte's residents. It should include showcases of circular innovations, recreational activities, educational facilities, and workshops that can facilitate pilot projects. The Barn should itself uphold the highest standards of circular economy performance: it should ideally be a zero waste building and designed according to circular building principles.
- **Secure funding and commitment for Charlotte's Innovation Barn.** There needs to be funding for the development of the site, but also sufficient resources for the further maintenance and operations side of the project.

Establishing Circular Programs & Staffing

For this transition to be successful, it is essential for the city to establish longer-term circular economy programs and create support roles within the government to facilitate this process. A lot of effort can also be expected of the business community and civil society, but a fully-fledged adoption of circular practices is not likely to happen on its own without initial leadership and guidance from the city.

- **Appoint Chief Circularity Officer.** To drive the strategy forward, the city should appoint a Chief Circularity Officer. The person in this position should be ultimately responsible for overseeing and implementing the circularity strategy.
- **Set up Circular Charlotte Program.** There should ideally be a Circular Charlotte Program facilitated by the city and overseen by the city's Chief Circularity Officer. This program should provide support functions to the city's entrepreneurs seeking to start circular businesses, it should coordinate stakeholder dialogues to better understand the challenges that companies are facing in moving towards circularity, oversee the city's progress on relevant KPIs, help establish financing mechanisms, convene sectoral dialogues to support the formation of partnerships, host a circular stakeholder network and take other measures in this direction. The different activities under the program should be defined based on the annual circular economy strategy. To ensure long-term commitment on this topic from both the public and private sectors, the program should ideally be funded for at least five years once it is initiated.
- **Work out actionable circular business cases in detail.** In Chapter 5 of this report, we have identified and described a handful of circular business cases that are promising for Charlotte and can be executed within current technological and legal limitations. These and other business cases should be worked out in further detail. Ideally, the city can identify profitable circular activities that it wants to participate in on its own. Revenues from these activities can be earmarked to further finance the circular transition. Business cases not suitable for the city can be co-developed as part of the Circular Charlotte Program and made available on the city's website or in a published handbook.
- **Identify and define circular financing vehicles.** Even if great business cases are identified, no action will take place without appropriate investment. Charlotte could initiate a dialogue with the banking community about establishing a revolving investment fund (or funds) focused on supporting circular businesses and innovation. There are potentially novel constructions possible if the city could provide some financial resources to "de-risk" the investments by taking on the role of a partial co-signer for circular business loans. This is one of many directions for circular financing. Other options include subsidies, tax breaks, grants and fellowships in partnership with philanthropic organizations, etc. The city should take an active role in helping to identify possible funding schemes for supporting circular innovation.
- **Begin discussions on reframing the next interlocal agreement.** Though the current solid waste interlocal agreement between Charlotte and Mecklenburg County does not expire for another decade, it is important to already conceptualize how this agreement could be modified in the future to facilitate circular innovation and understand what kind of outcomes are important to the stakeholders involved.
- **Establish competitions and awards for circular innovation.** The Circular Charlotte Program can host a variety of annual awards for circular innovation focused on different sectors (e.g., hotels, retail, manufacturing) or target groups (students, corporates, start-ups).
- **Develop neighborhood action plans.** To engage the local community in the circular economy, Charlotte should develop neighborhood actions plans together with residents of local communities. These plans should be based on an understanding of the context and specific features of each community and include actions for helping accelerate the circular economy locally. For example, some neighborhoods might want their own repair cafe or facility for sharing tools and appliances, whereas other communities may primarily focus on increasing local recycling rates.

Building Circular Infrastructure and Resources

In parallel to building alignment and commitment to the circular economy, the city should take steps towards creating the physical changes and hands-on programs that will get the movement going. This involves actions ranging from increasing collection and processing

capacity for specific waste streams to developing programs that lead towards circular job creation.

- **Set up a revolving fund for community garden establishment.** Community gardens can play an important role in the cycling of local organic waste (in the form of compost). This is one of the lower threshold circular activities that the city could support, which will also provide a range of social and health benefits to communities.

- **Scale up logistics and processing capacity for high-priority waste streams.** We have identified organic (food) waste, plastics, textiles, and concrete as some initial high-priority waste streams for Charlotte to focus on.
- **Set up task forces for priority waste streams.** We recommend that Charlotte set up a task force for each of the high priority waste streams. These task forces should include representatives from the government, private sector, and citizens, and should be asked to identify ways that collection and processing of these target streams can best be scaled up.
- **Support community centers in setting up centralized recyclable collection capacity.** Community centers, including churches and schools, should be encouraged to set up facilities for the collection of recyclable materials. The city should provide guidance on the types of materials that should ideally be collected (for example: food or textile waste), and create an incentive structure for participating groups.
- **Pilot for homeless employment in circular waste management.** The city is already discussing how to establish a rehabilitation program for the homeless by engaging them in activities around circular waste management. This project should ideally start with a specific waste stream (potentially linked to one of the business cases described in the next chapter), that can be processed in a high-value way.
- **Identify key infrastructure that needs to be invested in.** The outcomes of the waste stream task forces should ideally help identify the kinds of centralized infrastructure that it would most make sense for the city to invest in centrally. One example mentioned in stakeholder interviews is equipment for the pre-shredding of plastic, which would facilitate the ability of small recycling companies to develop.
- **Campaign for food waste reduction.** Though waste materials can be processed into high-value products, waste is best avoided to begin with. This is especially true when it comes to food. The city can set up a campaign for food waste reduction, making people aware of tools and apps available for avoiding food waste and by facilitating new enterprises that address food waste challenges.

- **Set up repair cafes.** The city should encourage the development of repair cafes, especially in underserved communities. This can provide a training opportunity for the development of new skills around the repair of specific products like clothing, furniture, or electronics.

Establish the Basis for Circular Monitoring

A final category of actions in this near-term phase is to establish the necessary tools to collect and evaluate data on how the city is progressing towards its goals on circularity. Without this insight, it's impossible to

understand which of the approaches described here are working and resulting in the greatest progress.

- **Establish new data collection protocol for material inputs and outputs for the city of Charlotte.** To be able to continuously monitor progress towards circularity, the city needs to establish a new data collection and monitoring protocol for material flow data as well as the other metrics that have been defined in the KPIs chapter. Ideally, the collection of this data would be largely automated and the results continuously displayed in a city dashboard. Different neighborhoods can also be monitored on their contribution to the city's overall score, helping define focus for where different actions need to be taken.
- **Invest in urban sensing and open data infrastructure.** To facilitate the tracking of data for monitoring circularity performance, the city should invest in sensor systems. These can be used to monitor the total quantity of waste and recyclables disposed throughout Charlotte and help improve waste management logistics.

Build Circular Charlotte's International Profile

As Charlotte makes progress towards its circular economy objectives, the city should make a point of gaining international visibility for its efforts: not only for the direct benefits it will bring in attracting talent and improving the city's international standing, but also as a way of sharing solutions that work. Other cities and regions will be able to learn from Charlotte's successes and failures, helping accelerate the transition to a circular economy worldwide.

- **International profiling through presentations and speeches.** Representatives from the city of Charlotte should take advantage of opportunities to speak abroad and share the story of Circular Charlotte. Some budget should ideally be set aside for a few international events per year.
- **Set targets around high performance on city rankings.** Charlotte should review the various criteria for different city ranking indices and ensure that they are aligned with its own performance goals.

MEDIUM-TERM ACTIONS

Once the baseline infrastructure for a circular economy in Charlotte is in place, the next phase of activity should build on this foundation. Developing educational and training programs, introducing policies and financing mechanisms, as well as building out Charlotte's innovation ecosystem and circular infrastructure are all important pillars of the medium-term actions we recommend here.

Develop Circular Education Programs

- **Scale-up aquaponics in schools programs for education.** Local initiative 100 Gardens is working to bring aquaponics installations (food production systems that combine fish and plant cultivation) into the city's schools. One of the primary goals behind this project is to create learning experiences for students to understand the interconnectedness of natural systems, add a hands-on aspect to science curricula, and introduce a range of practical skills in areas such as business and marketing. Scaling up this program is a straightforward way of introducing circular thinking in schools with a group that is already active in Charlotte.

- **Adjust school curricula to include circular education.** One of the most commonly mentioned requests by stakeholders is to adjust school curricula in Charlotte to include modules about the circular economy. This is an important step in changing the long-term attitudes of Charlotte's citizens and building the knowledge and skills that are needed to realize a circular economy. Adjusting the curriculum in local schools may be challenging in practice since curricula are defined at the state level. Even so, this is an impactful enough direction that these challenges are worth overcoming.
- **Develop new higher education programs focused on STEM skills and circularity.** Charlotte is currently lacking sufficient higher education programs focused on engineering and technology, which are essential knowledge areas for the circular economy. As we describe in the vision for a circular Charlotte, an important mid-term action would be to establish

new higher education programs focused on circular engineering and design. This would ideally be taken on as an initiative by local universities such as the University of North Carolina Charlotte.

- **Offer free circular construction and deconstruction classes.** Construction and demolition (C&D) waste is the largest single waste stream making it into landfill - not only in Charlotte, but in most cities. Circular construction techniques ensure that buildings are designed for disassembly and reuse, which will lead to the reduction of future C&D waste flows. Even with existing buildings that have not been designed or constructed in a circular manner, proper deconstruction practices can result in much higher quality material for reuse or recycling in new construction projects. Local NGOs, like the Goodwill Opportunities Center, could provide training on circular construction and deconstruction practices. Additionally, the city could sponsor training programs at relevant companies in the construction sector.
- **Start circular mentorship program for high school students.** The Equality of Opportunity Project, in addition to identifying Charlotte's lagging status on economic mobility, has shown the clear link between income and innovation. High potential students from low-income families risk becoming "Lost Einsteins": would-be innovators who were never able to realize their potential. One possible solution to this problem has been identified: providing high-potential students with access to mentorship and exposure to the way of thinking and skills that are needed in order to become innovators. A high school mentorship program would ideally connect students with companies and startups focused on the circular economy.

- **Establish trade skills training center for the Circular Charlotte brand.** Trade skills like carpentry, sewing, and shoe repair are important for artisanal-scale local manufacturing and product reuse. The Circular Charlotte brand, mentioned later in the roadmap, is a product label for all new products and goods made in the city following circular principles. A training center could teach individuals of all ages the necessary skills to make new products while also giving them the knowledge they need to do this in a truly circular way.
- **Culinary schools establish program for entrepreneurs in circular cuisine.** There are several well-known culinary establishments in Charlotte which could play a strong role in changes practices in the restaurant and food service sector towards reducing food waste. Chefs can be taught how to run more circular kitchens - with a focus on resource efficiency and waste reduction. These programs can also shine light on the many possibilities of new circular business models in food service: using food grown on-site, salvaging produce rejected for aesthetic reasons from farms or retailers, and creating haute cuisine from excess food purchased by retail stores.

Establish Circular Incentives and Policies

Some of the most important systemic shifts towards circularity involve changes in incentives and policy structures. When the "rules of the game" are designed to favor circular behavior, then this will take place much more naturally. Some of these actions may be quite challenging to implement and may require many years of discussion and lobbying, so it is important to look to other parts of the U.S. and the world where these kinds of measures have been successfully put in place and to get started on this path as quickly as possible.

- **Implement "untax" incentive system for citizens to recycle.** In Charlotte, and North Carolina more broadly, there is a strong aversion to new forms of taxation. Ultimately, however, taxes are an important policy instrument that could support the transition to circularity. A lower-threshold initial mechanism that can be tried is "untaxation" - providing refunds or credits to incentivize recycling behavior. For example, citizens could get credits for every bag of recycling they deliver to a designated drop-off point. The feasibility of this approach, and its exact mechanism, would need to be further explored.
- **Ban food wastes in restaurants.** Banning food waste in the restaurant and hospitality sector refers to making it illegal for these establishments to throw food or organic waste into the trash. All edible food would ideally be used as food: donated to homeless shelters or otherwise processed into products like soups, sauces, and preserves (potentially by a third party). All organic waste would be composted, biodigested, or processed into materials.
- **Develop circular procurement guidelines for retail stores.** One of the biggest sources of municipal solid waste is food and product packaging. The city could develop and disseminate circular procurement guidelines, encouraging stores to push their suppliers toward buying products with less packaging. This could lead towards a push up the supply chain for changes in product packaging. To encourage the adoption of

these circular procurement standards, the city can later host an annual award recognizing the retailers who have managed to reduce their waste flows most significantly.

- **Define circular building standards for Charlotte.** This measure is particularly important if Charlotte continues to grow at its current pace. All new buildings should eventually adhere to circular building standards, simplifying the process of extracting high-value materials once buildings are ready for renovation or demolition.
- **Abolish sales taxes on circular activities** (repair, refurbishment, etc). One measure that can be taken to incentivize the refurbishment and sale of second-hand goods is to remove the sales tax for all related products and services. This approach is currently being implemented in Sweden.
- **Develop circular procurement criteria for the city's own purchasing.** City governments are an important player in the local economy, buying a significant amount of local products and services. By only buying "circular" products and services, the city of Charlotte can help build the local market for these kinds of solutions while further raising awareness about the transition.
- **Ban on single-use plastics.** Though it may now sound controversial, a growing number of municipalities and even countries are implementing bans on single-use plastics. Within 10 years time, this will likely be a more acceptable action to take in Charlotte, and will also drive people and businesses to move towards more circular solutions.

- **Reward tiered pricing housing development.** An important part of circular development that should not go unrecognized is the importance of maintaining a diverse population through inclusive urban design. It is essential to have city centers where artists and makers can live alongside tradesmen, service workers, and professionals. To facilitate this, the city should consider policies that preferentially award development rights to projects that provide diverse types of housing alongside space for facilities like workshops and studios.
- **Revisit zoning regulations and land allocation to support circular activities.** The city should take a look at where zoning regulations may be hampering the development of circular initiatives by, for example, preventing the establishment of urban farms or clean, small-scale manufacturing activities. The zoning code should ideally be revised with the consideration of new technologies and how they might fit into the urban fabric differently than past options.
- **Stricter enforcement and fines.** Even today, it is technically illegal to landfill PET and HDPE plastics, but this is still broadly happening throughout Charlotte. The city should take a stronger stance on enforcement of existing laws as well as any new policies that are put in place to support the circular transition.

Further Develop Financial Support for Circularity

Financing is often one of the most significant stumbling blocks towards innovation. Here we suggest a small selection of topics and mechanisms to focus on with targeted circular finance vehicles.

- **Establish fund for setting up vertical farming projects in Charlotte.** Local food production in landless vertical farming systems can lead to multiple social benefits. If done properly, it can also reduce the environmental footprint of food production and serve as a means of recycling organic waste (as compost and liquid compost derivatives) within city limits. The city should consider setting up a dedicated fund for these types of projects.

- **Establish a loan program for local small recyclers to start up or scale up.** Small recycling companies will initially be at the core of Charlotte's circular transition and should be supported in starting and scaling up.
- **Establish a revolving fund for small-scale renewable energy and battery storage projects.** The circular economy ultimately needs to be powered using renewable energy. Projects on decentralized energy production and storage are an essential part of this transition and should ideally be financed by a city-wide revolving fund.

Build Innovation Ecosystem

An innovation ecosystem refers to the labs, accelerators, communities of startups, and the groups of entrepreneurs that will need to drive a large part of the development of a circular economy in Charlotte.

- **Establish innovation labs and accelerators.** Though Charlotte already has a number of accelerators and innovation labs, these should ideally expand their focus to specifically support circular economy initiatives, or dedicated innovation labs should be set up for this purpose.
- **Replicate the Innovation Barn model in other Circular Living Labs.** The Innovation Barn is going to be one of the most important visible showcases for the circular economy in Charlotte. The most successful aspects of this project can be replicated in other circular living labs that potentially focus on scaling up circular projects, or that are dedicated to handling specific waste streams, like organic waste or plastics.
- **Set up an entrepreneur helpdesk with support services for launching new businesses.** Starting a new business can be challenging - particularly if you do not have a lot of the basic knowledge about the legal, financial, and managerial aspects of running a company. The city could support would-be entrepreneurs with basic training on setting up a business, and launch a helpdesk to assist new companies with some of their administrative and legal questions.
- **Identify locations for circular industry park.** A circular industry park could be an important hub for new manufacturing activities. By co-locating different businesses in one place, you can also facilitate the trading of different material streams (through industrial symbiosis). The city should, in this mid-term phase, investigate what locations might be suitable for setting up such a park.

Further Develop Circular Infrastructure

Alongside all the regulatory and knowledge-centered efforts that need to take place to move towards a circular economy, there will continue to be many necessary changes to Charlotte's physical infrastructure to help bring about the transition to a circular model.

- **Begin investing in R&D in plastics, textiles, and construction waste processing.** The city should ideally set aside some of its own R&D funding for the recycling and processing of selected high-impact waste streams. This investment should ultimately yield profits that can offset its original cost.
- **Develop reverse logistics and storage to facilitate urban mining.** It is clear that additional sorting and storage facilities will be needed to, for example, stockpile components from buildings for later reuse. The city should ideally identify locations for these kinds of material hubs, considering where the optimal spots might be based in proximity to waste streams or new projects.

- **Invest in central infrastructure to increase quantity and quality of materials processed** (e.g. a plastic shredder, optical sorting, disassembly robots). As discussed in the barriers section, there are still some pieces of central recycling infrastructure that are not at a sufficient level of development for efficient material separation. At the same time, private businesses are often not able to afford this equipment. Charlotte can give all of these players a boost by investing in the centralized technologies that would be most collectively useful.
- **Introduce new collection systems to increase volumes** (e.g. bins with technologies or incentivized takeback systems). As technologies in waste collection advance, the city should look at implementing systems with tracking, or built-in incentive systems that reward people for depositing correctly sorted recyclables. The city can run pilots with several technologies before settling on a direction to see which approach is most successful at increasing collection volumes and material purity.
- **Build circular marketplaces** (including an upcycle mall). To drive the growth of a circular economy,

there also needs to be a growing demand for circular products. Setting up marketplaces for products made in a circular way or for products that have been refurbished or remanufactured is one way to achieve this. One possible concept is an "upcycle mall": a shopping mall where every store sells only refurbished or second-hand goods.

City-Wide Innovation Projects

Aside from broad support in the development of circular infrastructure, Charlotte should ideally take on a few iconic projects that advance the city's progress towards a circular economy in highly visible ways.

- **Begin a pilot of Charlotte Coins.** The idea of the Charlotte Coin, as described in the vision section of this report, is to have a complementary currency that can be used to reward participation in recycling schemes and be traded in for discounts on circular products or services. The city can host a pilot of this concept, or find a suitable NGO or other organization to support in this effort. **Fully establish the Circular Charlotte brand for products.** Having a brand with clear standards that can only be applied to local products that are also made in a circular way is something that can benefit the city by boosting the local economy and increasing outside visibility.
- **Address wastewater nutrient and materials recovery.** Wastewater contains many different valuable resources like nitrogen, phosphorus, heat, fiber, and even metals. These should ideally be harvested and reprocessed into valuable products. Alternative sanitation projects around the world are currently experimenting with resource extraction from wastewater. To become truly circular, Charlotte should eventually also address this important (and sizeable) resource flow.

- **Begin the first Charlotte smart grid pilot.** A pillar of the circular economy is to maximize the amount of renewable resources used in the system, including renewable energy. A smart grid can facilitate efficient use of energy and the management of many individual sources of power generation (such as household photovoltaic arrays). Charlotte should support larger-scale transitions in the city's utility infrastructure.
- **Start to develop protected bike lane routes throughout the city.** Carbon-neutral mobility will be much easier to achieve in Charlotte if bicycle travel is made safer and easier. The city should lay the groundwork in terms of urban planning as early as possible to prepare for the construction of a city-wide network of bike lanes.

Further Develop Circular Monitoring Capabilities

After Charlotte's circular economy performance has already been monitored for several years, it will become clearer as to which metrics are most useful and which ones need additional refinement. With data collection infrastructure in place, the city should aim to further automate its monitoring capabilities and make the information more easily accessible to the city's residents through a public Circular City Dashboard.

- **Develop a Circular City Dashboard.** Ideally, Charlotte's Circular City Dashboard should be a publicly accessible portal containing all available information on the city's circular economy performance. Residents should be able to see the relative performance of their own neighborhoods, find circular marketplaces and resources, and connect with local initiatives. The Dashboard would also play an essential role for city officials, providing feedback on which policies and incentives are working effectively.

LONG-TERM ACTIONS

The further we look into the future, the more speculative our recommendations naturally become since it is impossible to predict how technologies will develop and how society will change over time. Even so, there are some actions that we imagine Charlotte taking on that we think will become relevant a decade or more from now. Some of these are briefly described here.

New Technologies

- **A small-scale incinerator with energy recovery for remaining non-recyclables.** It is unlikely to become possible to ever fully recycle 100% of all materials. Some waste streams will remain that are hazardous, degraded, or highly contaminated. Yet burning these materials for energy is still preferable to landfilling. For these reasons, it would eventually be a good idea for Charlotte to investigate installing a small-scale incinerator or gasification unit, which could handle the remainder of the materials that cannot be used at high value. This incineration process should result in air quality that is equal to or better than the ambient air.

- **Smart sorting containers at neighborhood level.** As Internet of Things (IoT) technologies advance, trash collection units will become increasingly smart: they will be able to report how full they are and predict when they will need to be emptied. They may even be able to pre-sort or reject inappropriate content deposited by citizens. Charlotte should implement these kinds of technologies as they become available and financially feasible to use. They will increase the quality of recyclables and improve the efficiency of collection logistics. They can also be paired with Circular Charlotte Coins, giving households rewards for recycling.
- **Advanced scanning and sorting technologies for recyclables.** Artificial intelligence, machine learning, and robotics are advancing rapidly. Thse technologies will make it possible to sort post-consumer wastes much more effectively and safely. Charlotte should conduct tests and support R&D in this area, and ultimately move to adopt these technologies as they become available.
- **Pilot for an on-demand self-driving public transport system.** A large part of the environmental and health impact in cities comes from the thousands of cars that emit air pollutants, take up space when parked, and lead to significant amounts of waste when they are disposed of at the end of their useful lives. By adopting a public transport system with on-demand self-driving vehicles, Charlotte can provide citizens with the flexibility of traveling when and where they want, while also reducing the total vehicle stock in the city.

Continued Innovation

- **Charlotte starts developing circular industry park.** Fully scaling up circular activities will eventually require larger-scale industry. Charlotte should make space for the development of new, circular manufacturing by opening up a circular industry park, which should itself be designed as a zero waste facility.
- **Emergence of full-service living concepts.** Full service living concepts are apartments or homes where appliances, furniture, and even transportation or food delivery services are provided as part of a package deal. This can help extend the useful lifespan of different products, encouraging companies to design and select equipment that can easily be maintained and upgraded, ultimately reducing waste. It would also increase convenience for residents.As these concepts emerge, this is one pathway that can be explored by Charlotte.

- **Establish a new engineering school at UNCC focused on circular design.** Ultimately it is essential for Charlotte to develop a stronger basis in STEM education and attract more science and engineering students to the area. To achieve this, UNCC or another local university should work towards establishing an engineering and design school with a strong circular economy focus.

- **Launch a revolving fund for waste-to-products companies.** Funding new initiatives will remain an essential prerequisite for innovation. Charlotte should continue to provide long-term financial resources for this purpose, ideally in the form of a revolving fund.

Advances in Circular Policy

- **Adopt circular procurement criteria for all purchasing.** City government is one of the driving forces in any urban economy - largely through its purchasing power. If every dollar spent by the city helps build the demand for circular goods and services, Charlotte's advances toward circularity will rapidly accelerate. The city should define and phase in purchasing guidelines for all products and projects (e.g., construction of new buildings or infrastructure).
- **Require new buildings be built to circular standards.** With circular construction and demolition knowledge becoming more widespread throughout the city, Charlotte should move to require all new buildings to be built to circular standards.
- **Increase waste collection fees (pay-as-you-throw).** As waste collection, sorting, and processing infrastructure becomes more convenient to use, the city should dial up the incentives for all citizens to participate in circular resource management. Pay-as-you-throw schemes have been criticized by some, but also shown to be broadly effective in increasing participation rates in recycling programs.

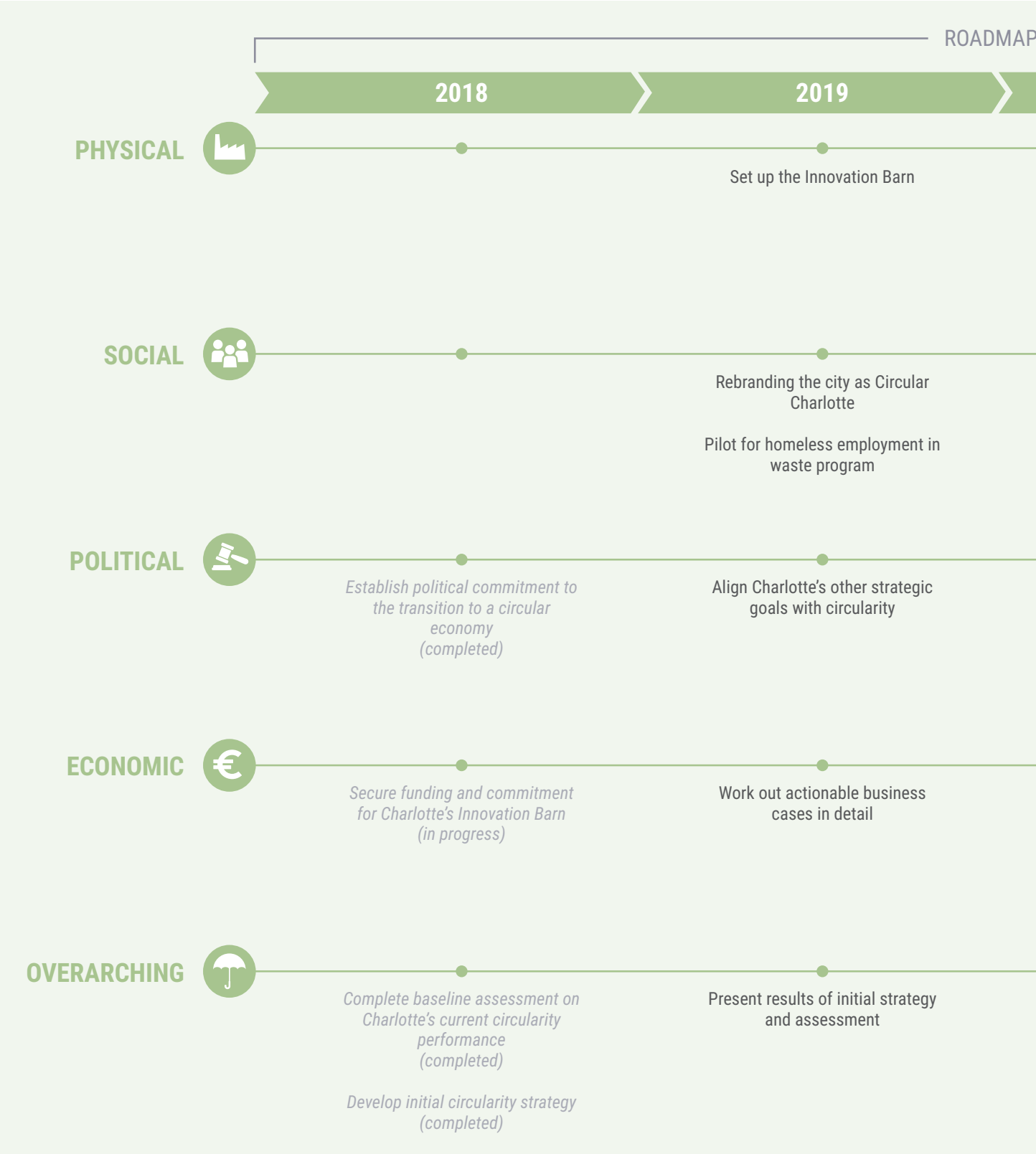
Circular Milestones

- **City of Charlotte handles all recyclables locally.** With advances in collection, sorting, and remanufacturing, Charlotte can process and recover all value from recyclables locally.
- **Charlotte begins taking and processing recyclables from nearby counties.** Once Charlotte has the infrastructure to effectively process all of its own waste materials in a circular and high-value way, it can start to provide this service to neighboring cities and potentially counties beyond Mecklenburg.
- **Landfills are closed and redeveloped.** If all of the strategies described here are implemented and working, the city and county should eventually no longer have the need for landfills. All residual wastes should be processed in some way, and at the very least used for clean energy generation.

- **Charlotte develops new ten-year circularity strategy.** Even while updating annual action plans, it will eventually be time for Charlotte to take a step back, evaluate its progress, and develop a new 10-year strategy for progressing towards a circular economy. This process should likely be repeated every 10 years or so.

SHORT-TERM ROADMAP

Charlotte's transformation to a circular city clearly cannot take place overnight. Short-term actions should focus on building awareness among the city's citizens, business owners, and other key stakeholders on what the circular economy is and the different opportunities it can provide, as well as laying the groundwork for tackling some of the barriers described in the previous section. In addition, it is essential to identify tangible actions, showcases, and



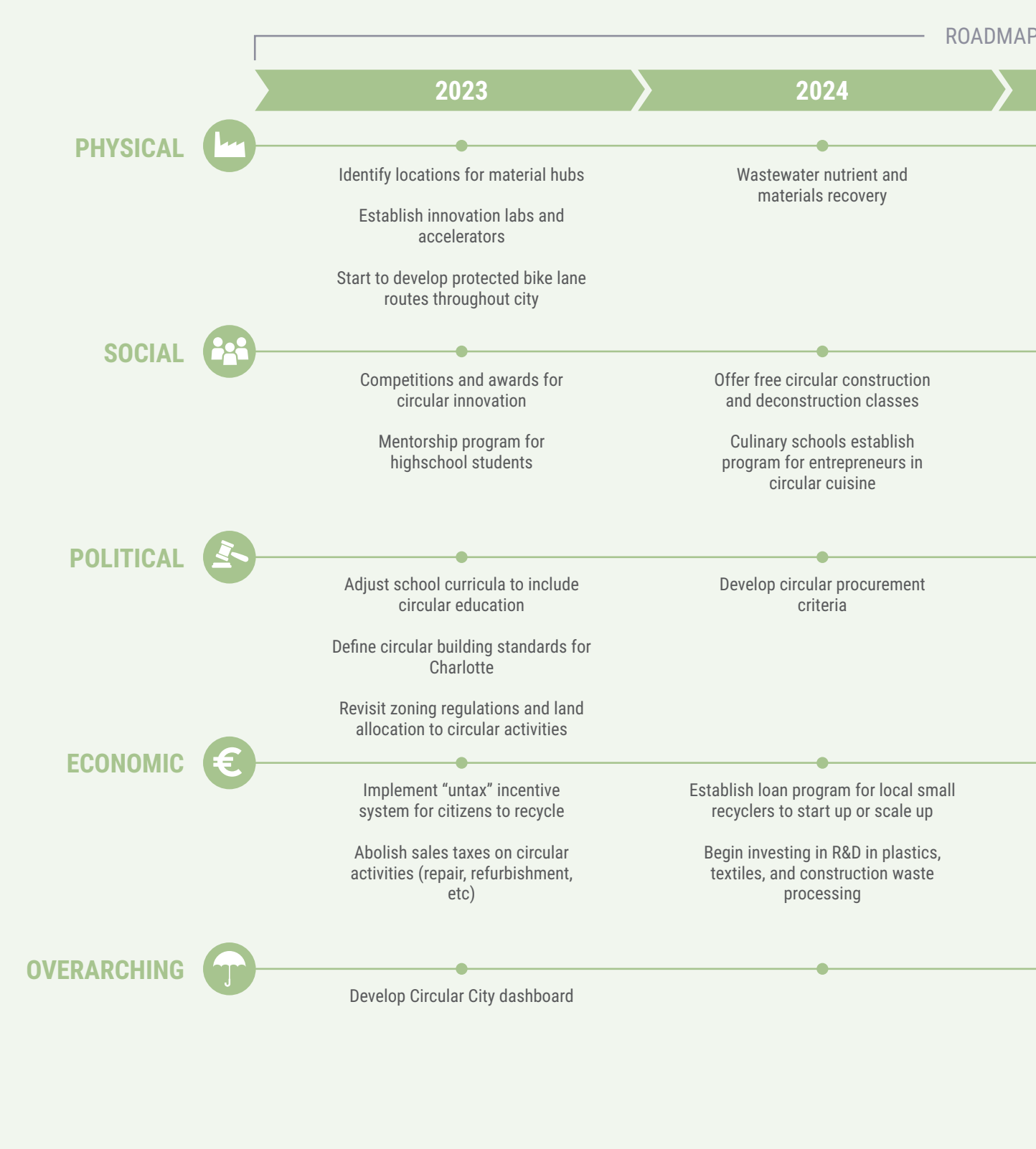
circular business cases that can be executed quickly in order to build support for the approach and demonstrate its value. Further steps should include capacity building and efforts geared at longer-term transformation, such as neighborhood action plans, the establishment of new partnerships and institutions, and monitoring programs to track the city's progress on circular economy metrics (i.e., the KPIs presented in Chapter 2).

SHORT-TERM (0-5 YEARS)

2020	2021	2022
Set up repair cafes	Replicate the Innovation Barn model in other Circular Living Labs Scale up logistics and capacity of high-priority waste streams	Identify key infrastructure that needs to be invested in Invest in urban sensing and open data infrastructure
Communications campaign for Circular Charlotte Social campaign	Circular Charlotte Program Campaign for food waste reduction	Establish circular stakeholder network Support community centers in setting up centralized recyclable collection capacity
Identify Chief Circularity Officer for the city Neighborhood action plans	Setting up task force on priority waste streams (e.g. food waste)	Begin discussions on reframing next interlocal agreement
Define circular investment vehicles Set up revolving fund for community garden establishment		
New data collection protocol for material inputs and outputs for the city of Charlotte	International profiling through presentations and speeches	

MEDIUM-TERM ROADMAP

Once the baseline infrastructure for a circular economy in Charlotte is in place, the next phase of activity should focus on building on this foundation. Developing education, training programs, introducing policies and financing mechanisms, as well as building out Charlotte's innovation ecosystem and circular infrastructure are all important pillars of the medium-term actions we recommend here.

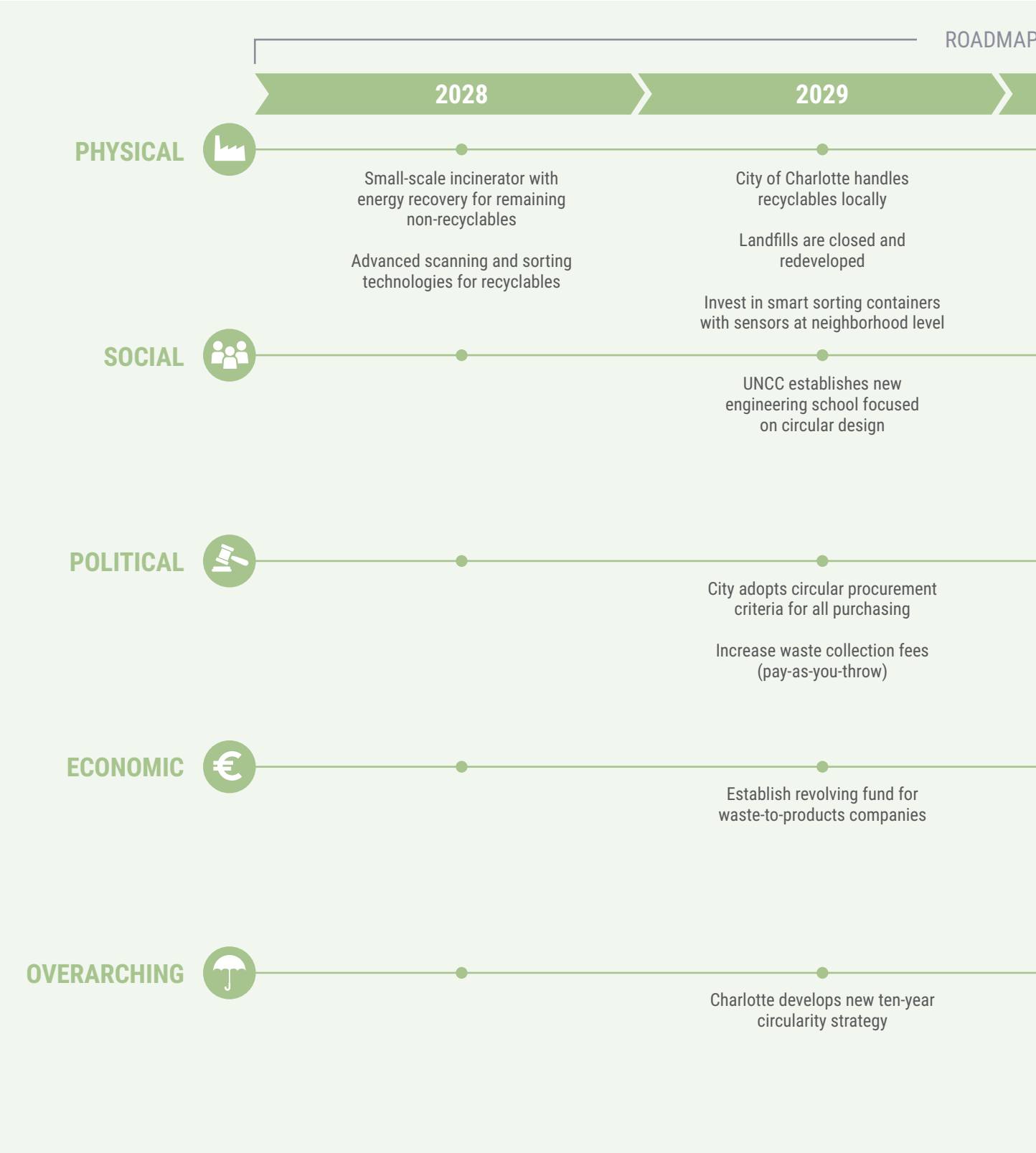


MEDIUM-TERM (5-10 YEARS)

2025	2026	2027
Develop material hubs for waste collection and storage Invest in central infrastructure to increase quantity and quality of materials processed	Build circular marketplaces (incl. upcycle mall)	Identify locations for circular industry park First Charlotte smart grid pilot
Fully establish Circular Charlotte brand for products Scale-up aquaponics in schools programs for education	Offer free circular repair and remanufacturing classes Set up entrepreneur helpdesk with support services for launching new businesses	Establish trade skills training center for the Circular Charlotte brand
Ban on single-use plastics Ban on food wastes in restaurants	City rewards tiered pricing housing development	Stricter enforcement and fines
Begin pilot with Charlotte coins	Establish revolving fund for small-scale renewable energy and battery storage projects	New fund established for setting up vertical farming projects in Charlotte

LONG-TERM ROADMAP

The further we look into the future, the more speculative our recommendations naturally become since it is impossible to predict how technologies will develop and how society will change over time. Even so, there are some actions we imagine Charlotte undertaking that we think will become relevant a decade or more from now. This is also the period in which some important milestones can be met.



LONG-TERM (10-15 YEARS)

2030	2031	2032
Start developing circular industry park Begin taking and processing recyclables from nearby counties		Emergence of full-service living concepts Pilot for on-demand self-driving public transport system
Require new buildings be built to circular standards		
International profiling through presentations and speeches		

BUSINESS CASES

DEVELOPING BUSINESS CASES FOR CHARLOTTE

Until now, we have considered the shift to circularity from a high level, by asking ourselves questions such as:

- Which **materials** are ending up in the landfill and why?
- How much material **value** is ending up in the landfill each year?
- How many **jobs** could we create if **all** of this material was recycled into new products?
- What **systemic changes** are needed to enable circularity in Charlotte, for example in policy, education, and infrastructure?

While this high-level thinking is necessary for the city to change the environment into one which can structurally support circularity, local entrepreneurs and communities will be the ones who actually implement circular activities in the city. For this reason, it is necessary to dive deeper into the costs and benefits of specific activities and supply chains.

In this chapter, we present a small selection of business cases, covering just a small share of the material flows of the city. The selection of these cases was made to address some of the most impactful or problematic material flows and on the basis of interest from local stakeholders in specific supply chains that came out of interviews and the workshops hosted as part of this strategy work.

For each business case we:

- Describe the current context and the new scenario we envision
- Present a few examples of similar cases being implemented in other regions
- Explore some of the barriers to implementation and how these can be overcome (for example with structural interventions)
- Describe how we see the case functioning and the benefits each could bring for society and the environment

These are meant to give an indication of the order of magnitude of costs and benefits that each scenario can deliver in order to stimulate local government and entrepreneurs to take action on promising activities. However, in order to actually implement them in the city, they will need to be worked out in further detail with all relevant partners actively participating in giving them form.

BUSINESS CASE: CLOSED-LOOP TEXTILES CHAIN

DESCRIPTION

Charlotte has been an important part of the historical development of the textiles industry in the United States. Today, it is still an important sector for the region; Charlotte ranks 2nd in U.S. cities for employment in the textiles sector (U.S. Cluster Mapping, 2018). Becoming a frontrunner in circular textiles can be one of the most promising ways for Charlotte to take the first steps towards being recognized as a leader in circularity.

Around 57,000 tons of textiles disposed of in Charlotte end up in the landfill each year. Of this amount, 43% is reusable and should ideally end up in secondhand markets. For the textiles that are worn, stained, and damaged, however, there should be a pathway for recycling them into new textiles. To make this possible, there are some barriers to textile recycling that need to be overcome:

- Collection from a large number of households, where volumes are so small and irregular that logistics would be inefficient.
- Identifying and separating the types of textiles after collection. The technologies to properly sort textile types using sensors is still under development, while hand sorting is imperfect in the absence of labels.
- Technology availability for textiles recycling beyond pure fiber types. While technologies exist for separating polyester and cotton, the most common blend, these are not yet at commercial scale (see HKRITA, Chalmers university, Ioncell-F) . For other blends, the technologies are even more limited.

For these reasons, a first step for Charlotte could be a limited circular model for sources of textiles that are easily tracked, standardized, concentrated for collection, and can be of single material types. The best options are textiles used in hotels, medical facilities, and uniforms (public employees, sports clubs, hospitality, etc). Therefore, two value chains can be established: one around pure cotton streams, which are commonly used in linens and towels, and one around polyester textiles, mainly uniforms.

On the longer term, as technologies for separation and recycling advance, further product types can be added to the circular value chain. This case offers an opportunity to set into place the logistics model for tracking and collecting materials in a way that is scalable, and establishing partnerships between textile users, recyclers, producers, and logistics. Producing and reprocessing textiles locally instead of importing linens and apparel, and exporting textile waste, offers new opportunities for increasing local employment.

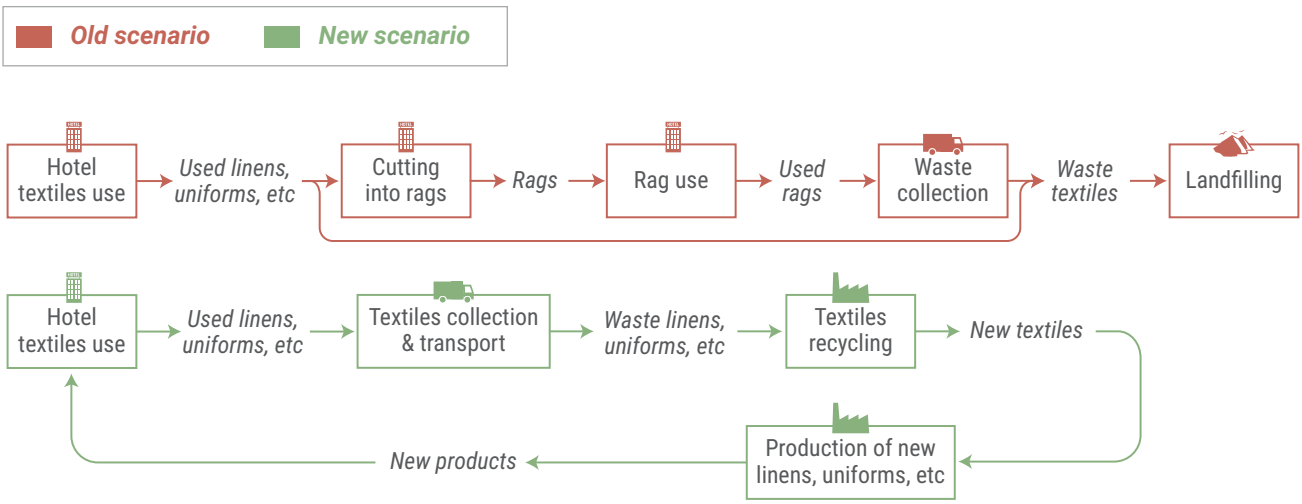


Figure 9. Overview of the Closed-Loop Textiles Chain Case

EXAMPLE CASES

Dutch Awearness is a "chain manager" in the Netherlands, designing circular workwear made from 100% polyester, which is essentially leased, rather than sold, and recovered at the end of life to be recycled into new workwear. To track products, Dutch Awearness has designed a supply chain management process and tool called the Circular Content Management System (CCMS), which uses unique barcodes to track material, impact, and location data.

Key stats

- *Saves up to 95% of the water and prevents up to 63% of the CO_2e emissions*
- *Can be recycled up to 8 times and produces nearly zero waste*

Econyl is a company making 100% recycled nylon fibers for apparel and carpets, designed for recyclability at the end of life. Raw materials for the products come from post-consumer sources, including nylon nets fished out of landfills and the ocean. Econyl fabrics have ended up in apparel by H&M and carpets by Desso.

Key stats

- *Saves 7 barrels of oil and 5.7 tons of CO_2e emissions per ton of recycled fiber*
- *Reduces global warming impact by 80% compared to virgin nylon*

Repreve is a polyester textile brand by the fiber producer Unifi. This fabric is made using recycled post-industrial and post-consumer PET waste. Repreve offers a range of textiles made from polyester and is currently working with dozens of apparel producers to deliver high-performance fabrics.

Key stats

- *80% of polyester comes from post-industrial waste, 20% from post-consumer waste*
- *Unifi has recycled more than 10 billion PET bottles*
- *Energy saved is enough to power 95,000 homes for a year*

CONTEXTUAL ASPECTS

Charlotte and its surrounding areas are home to companies active in the recycling of post-industrial polyester and cotton fibers. These fibers are then converted into new yarns which are upcycled by regional manufacturers into new products. The existence of these companies points to the infrastructure that is currently available to process future recovered textiles, however increased capacity may be needed once scaled production takes hold.

The barriers that remain relate to establishing partnerships and logistics (including tracking materials) that allow for creating a truly circular model. A logistics model needs to be established that can ultimately prove attractive for all partners in the chain by:

- Reducing waste management costs for organizations in addition to advancing a new sustainable initiative for Charlotte and the surrounding region.
- Ensuring higher supply and demand of high-value post-consumer fibers for textile-recycling companies. Ideally, these are designed for easier disassembly and processing.
- Providing reliable and affordable secondary inputs to textiles manufacturers and providing an incentive to source recycled fibers and design new products for material recovery at the end of life.

IMPLEMENTATION IN CHARLOTTE

Charlotte already has all the pieces in place that are necessary for creating circular textile value chains. The main thing that is missing is a strong "chain manager" that can work with parties from procurement, to waste logistics, to recycling, and producing new products.

A full supply chain approach is necessary to tackle the challenge of making textiles circular. They should be designed in a way that makes it possible to easily recycle, for example by avoiding blended fabrics for which recycling technologies are not at the right scale, or treatments that impact recyclability. They should be collected in high enough volumes that logistics is not cost-prohibitive and that makes it attractive for a continued partnership with recyclers and producers of the textile products.

We think that for a new recycling business, or "chain manager", starting with a few good partnerships would be the best starting point as it simplifies logistics. Examples of partnerships could include large textile users such as the City of Charlotte (uniforms for public service employees) or hotels and hospitals (towels, linens, and uniforms).

We calculated a scenario where 20% of the yearly wastes from hotel and hospital linens and towels are collected, as well as 20% of the uniform wastes from construction, police officers, manufacturing, hospitality, and health

Table 1: Closed-Loop Textiles Costs and Benefits

COST	VALUE
Investment costs	$10,000
Rent	$30,000
Personnel	$112,000
Fuel and utilities	$9,000
Payments to 3rd parties	$3,260,000
Total	$3,411,000

REVENUE	VALUE
Revenue from collection	$29,000
Revenue from product sales	$5,400,000
Total	$5,429,000
Return on investment	
Payback period	

care. In this scenario, a total of 210,000 lbs per year could be collected for processing, including 9 tons of towels, 8 tons of bed linens, and 88 tons of uniforms.

If a maximum of 10,000 lbs are held at a time, then the space requirement will be approximately 1000 ft^2, with a rent cost estimated at $12,000-$18,000/year. Utility costs are estimated at around $1,700/year.

If the collected towels and linens were sold as scrap, the value would only be around $11,000, which would not be enough to cover even the running costs of collection and storage. However, most linens and towels are discarded when they are still usable materials and reselling these may be the best option. If 50% is sold at 40% of the original selling price, this would return $29,000 in revenues.

For the uniforms, the best option is fully recycling these into new polyester uniforms. If they sell again at the original sale price, the value would end up being $10.5 million in revenue. The recycling business could outsource part or all of this processing, or purchase equipment and hire additional staff. This part of the business case requires further investigation.

OPPORTUNITIES

If a textiles recycling chain manager starts small with collecting, processing, and reselling around 100 tons/year as in this business case, this will already result in immediate environmental benefits by diverting waste from landfill and avoiding the embodied impacts of virgin textiles production. Additionally, it would create a small number of jobs directly (and indirectly through outsourcing textiles processing).

By reusing cotton towels and bed linens, 150 tons of CO_2e, more than 275,000 gallons of water, and 79 acres of land use can be averted upstream by avoiding new virgin textile production. Recycling polyester instead of producing virgin polyester fabrics saves more than 1,000 tons of CO_2e and 70,000 gallons of water per year.

However, the real benefit lies in the learning opportunity that this business case provides. It could be the starting point for expansion into other textile recovery programs, for example collecting post-consumer textile waste rejected as secondhand clothing. It also provides a platform for engaging in conversation with parties producing textiles to strategically design products with a regenerative life-cycle in mind, ensuring the reuse or recyclability at the end of life

Table 2: Closed-Loop Textiles Opportunities

OPPORTUNITY	VALUE
Total waste diverted from landfill (lbs/year)	210,000 lbs/year
Potential profits from case ($/year)	$201,800
Total jobs created (#)	9
CO_2e emissions saved (tons)	1,226
Water use avoided (gallons)	345,341
Land use prevented (acres)	79

BUSINESS CASE: UPCYCLING FOOD WASTE INTO FEED

DESCRIPTION

Every year, nearly 150,000 tons of food waste from Charlotte households and small businesses ends up in landfill, with additional waste coming from other commercial entities and organizations. This is an enormous problem in terms of environmental impact, as decaying waste in the landfill results in high amounts of methane emissions, which is a greenhouse gas 25 times more potent than CO_2e.

Additionally, nutrients in this food waste are no longer recoverable once they enter landfill. The loss of phosphorus in particular is problematic from an economic standpoint as this essential nutrient is mined from limited stocks globally and will come up against scarcity issues in the medium term (global stocks are expected to last another 50-100 years, Cordell et al. (2009)). From a circular economy perspective, all food wastes should ideally make it back into cycles for food production.

Composting has been implemented in Charlotte with initiatives to increase household composting and public composting projects, for example at schools. Additionally, companies like Earth Farm Organics are processing large amounts of compost from households and commercial organizations, while Crown Town Compost has established household and small business food waste collection programs. While these programs should be structurally supported and scaled up, other higher-value products besides compost will need to be developed in order to fully close nutrient cycles and provide a strong incentive for organic waste separation.

An alternative application for food waste is its use as feed for insects called black soldier flies. Black soldier fly larvae eat any kind of food waste and grow quickly to the prepupae stage where they consist of about 42% crude protein and 29% fat (Wang & Shelomi, 2017). These larvae are an excellent source of feed for animals like, pigs, poultry, and fish (Veldkamp et al., 2012). If Charlotte diverted waste to black soldier fly larvae production for feed it could result in significant impact reductions, in addition to creating new employment opportunities and providing a higher revenue to justify expansion of existing food waste collection programs.

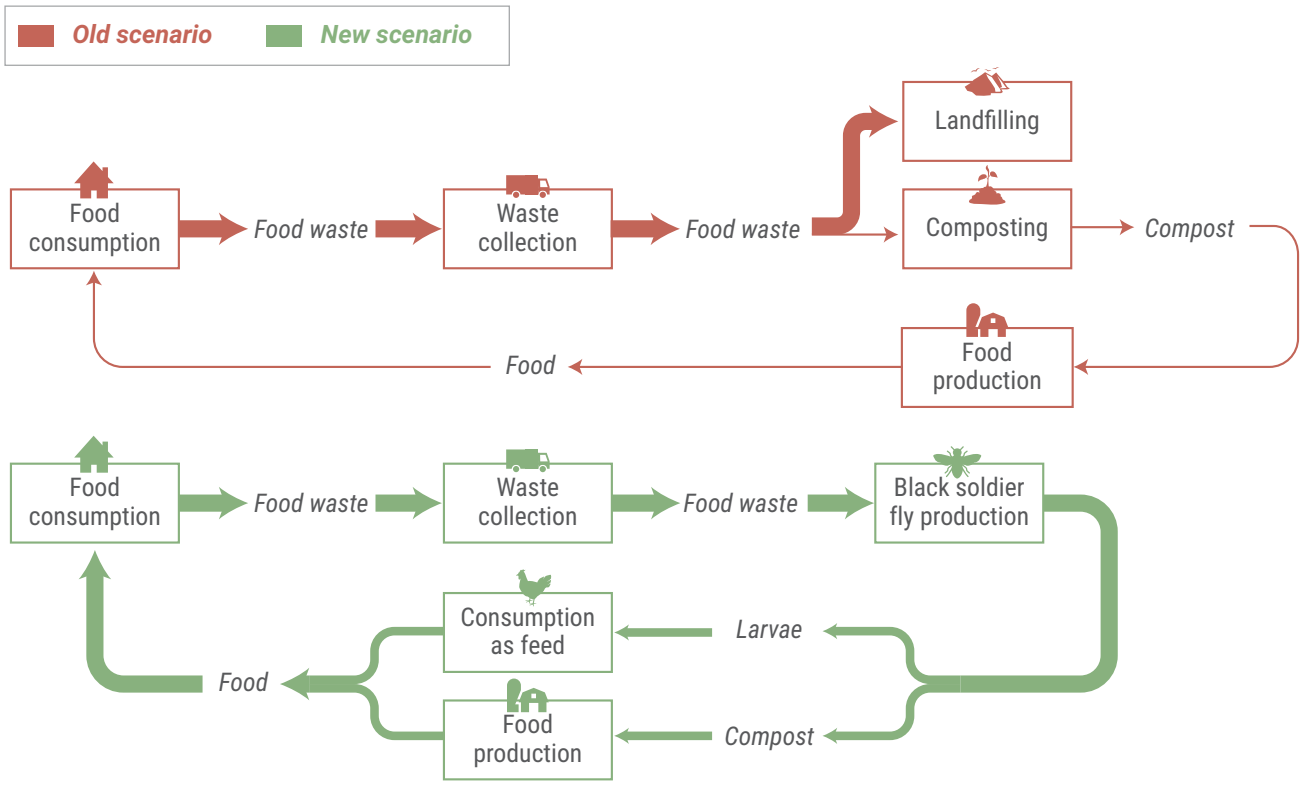


Figure 10. Overview of the Upcycling Food Waste into Feed Case

EXAMPLE CASES

Protix has been working on the breeding and application of black soldier fly larvae and upgrading into products since 2009. In 2017, they acquired $50.5 million in funding, which is the largest investment in this sector (Burwood-Taylor, 2017). Increasingly, they are collaborating with research institutes to find more high-value applications for black soldier fly larvae, eg. in meat substitutes and textile coatings (Protix, 2018).

Key stats

- *Protix sells feed products in over 12 countries*
- *Protix produces 1,600 tons of larvae annually at their location in Dongen (Salmon Business, 2017) using around 8000 tons of biomass.*
- *In their new location, Protix will grow insects on 15,000 m2, with 80 employees (Salmon Business, 2017)*

EnviroFlight was founded by Glen Courtright in Ohio, US in 2010. EnviroFlight started out by selling larvae as specialty feed for backyard chickens and exotic pets at $20,000 per ton (Warner, 2014), partly because it could still not be sold as regular feed for livestock. Now they sell larvae as feed for both livestock and pets. On the long-term they want to facilitate the use of the technology by selling consulting and hardware (Warner, 2014).

Key stats

- *Opening the first commercial scale facility in 2018*
- *Using post-industrial food waste from breweries and food processors*
- *Expects the price for larvae-based feed to reach around $1300/ton once the market has adapted (Pryer, 2015)*

Enterra is a Canadian company that was founded in 2007 by Brad Marchant after a conversation with environmentalist David Suzuki about problems with conventional aquaculture (Tossel, 2013). In 2014, they secured $5 million in funding to start a commercial scale pilot facility which can handle up to 54,000 tons of food waste. Recently the company acquired permission to sell products in Canada, the U.S., and Europe.

Key stats

- *In 2015, Enterra was diverting nearly 40,000 tons of food waste from the landfill (Colvin, 2015)*
- *Enterra can convert 40,000 tons of food waste into nearly 2,000 tons of meal product, 1,100 tons of food oil, and 3,300 tons of fertilizer (Tossel, 2013)*

CONTEXTUAL ASPECTS

Over the last eight years, innovative companies have been working hard to find the right technology for facilitating larvae production, which has resulted in the development of commercial-scale operations. The main technical challenge remaining is making sure the feedstock given to larvae can ensure consistency in nutritional characteristics (such as protein content). Without this assurance, it will be difficult to get farmers to adopt black soldier fly larvae as feed (Ford, 2018).

The main barrier to successfully implementing this business case is regulatory. Companies have been lobbying for regulatory change that would make it possible to sell larvae products in different applications using different production models, and have largely been successful in other countries. However, there are still challenges remaining to ensure the larvae are safe as feed, for example ensuring they do not accumulate heavy metals (through the substrate they are grown on), or develop infections (through plant hygienic conditions).

In the United States, the Food and Drug Administration (FDA) has only approved the use of larvae as a feed for salmon and can only be fed on feed-grade substrates (Wang & Shelomi, 2017). This limits the opportunities for producing and selling black soldier fly larvae and also creates a bottleneck in terms of meeting regulatory requirements for production. In the short term, two options are possible:

- Only using pre-consumer waste (for example from food processors), or
- Using the larvae in other applications, but not selling it on the market as feed

Depending on which pathway is taken, different types of infrastructure would need to be established. If post-consumer food waste is used, logistics for collection need to be expanded, while the business case for the larvae is not as strong. In this case, local regulatory measures, such as requiring restaurants and cafes to separate food waste (as Austin has done as part of the zero-waste program), could be necessary.

If pre-consumer waste is used, the logistics are easier (collection from a smaller number of entities) and the business case is stronger (larvae can be sold as feed on the market), but the scope and impact reduction potential are drastically reduced.

IMPLEMENTATION IN CHARLOTTE

The business case involves the construction of breeding facilities, with a starting capacity of 55,000 tons of food waste per year (around a third of the food waste currently ending up in the landfill). The facility can produce 11,000 tons of wet larvae or around 3,000 tons of dry larvae per year and employ around 150-250 people (Protix, 2018). As EnviroFlight is producing about 12 tons larvae/ft^2/year (Warner, 2014), in total this would require a space of around 132,000 square feet.

The investment for the facility is estimated to be around $2,000,000 - $6,000,000 and can generate revenues of $4,000,000 - $7,000,000 per year, depending on what products are produced (Protix, 2018). Operational costs are estimated at around $4,800,000 per year. The best option is to work with an existing technology and process such as EnviroFlight or Protix.

It is important to ensure a steady stream of food waste to keep the production running at a steady pace. Crown Town Compost and Earth Farm Organics may be good partners, as these companies are already handling food waste from households and small businesses (Crown

Table 3: Food Waste to Feed Costs and Benefits

COST	VALUE
Investment costs	$2,000,000 - $6,000,000
Rent	-
Personnel	$3,700,000 - $4,500,000
Fuel and utilities	$724,400
Payments to 3rd parties	-
Total	$2-6 mln + $4.4-5.2 mln yearly

REVENUE	VALUE
Revenue from collection	$667,000
Revenue from product sales	$4,000,000 - $7,000,000
Total	$4.7 - 7.7 mln
Return on investment (10 yrs)	114%*
Payback period	6 years*

** Based on a cautious financial projection using mid-range values for the parameters in the table.*

Town) and larger companies and organizations (Earth Farm).

Currently these companies get revenue from collection fees (which accounts for the largest share of revenues) and from sale of the compost produced. If their share in revenues from black soldier fly larvae is high enough to reduce collection costs for companies and households, then participation may increase. Otherwise, policy measures may need to be put into place to incentivize participation.

If a process using pre-consumer waste (from food processing) is put into place, companies like supermarkets, Snyder's Lance, Coca Cola, or Walmart might be good partners to include. In this case, one partner may be sufficient for a pilot stage.

The larvae can be used live or dried and used as feed or can be pressed to extrude fats and concentrate the protein in pellet form (producing a set of higher-value products). The two main outlets for products are as feed for poultry or aquaculture as a replacement for fish meal. Fish meal costs around $1,500-$2,000 per ton. However, producers may be hesitant to switch to black soldier fly larvae unless it also presents a clear cost saving. It may be more reasonable to assume a price of around $1,300/ton.

The poultry industry is the strongest agricultural industry in North Carolina and partnering with North Carolina Poultry Federation might be a good starting point to establish a strong connection to the customer segment.

Aquaculture is a second interesting partnership direction to pursue. Unlike pigs and poultry, fish cannot obtain the protein they need from soy and cereal grains (Burtle et al. 2012). Aquaculture is also increasing in popularity and the link with the aquaponics project planned for the Innovation Barn and projects such as 100 Gardens (which is using aquaponics to teach school programs about science, math, and more) makes it a more interesting case.

Finally, other markets could include pet stores (for the larvae), farms (fertilizers), cosmetics producers (fats), and pharmaceuticals (Omega 3, 6, and 9 fatty acids).

OPPORTUNITIES

If 50,000 tons of food waste is diverted to black soldier fly larvae production, this will reduce the amount of waste going to landfill by 5.3% and save the municipality $1.65 million in tipping fees. At an emissions intensity of 1.792 tons CO_2e/ton food waste (World Resources Institute, 2015), this means that nearly 90,000 tons of CO_2e emissions can be prevented per year through diversion from landfill.

An additional 7,000 tons of CO_2e is saved from the 6,800 tons of poultry feed that can be replaced by black soldier fly larvae. The replacement of poultry feed also saves about 41,000 gallons of water per year and 3,200 acres of land.

In total, this could generate $200k - $2.5m in profits per year and create 150-250 new jobs in production, as well as an estimated 83 additional jobs created in food waste collection.

It should be noted that while this business case involves large-scale processing, it only covers a third of local food waste and will need to be implemented alongside other initiatives to fully close local nutrient cycles.

Table 4: Food Waste to Feed Opportunities

OPPORTUNITY	VALUE
Total waste diverted from landfill (lbs/year)	100 million
Potential profits from case ($/year)	1,200,000
Total jobs created (#)	233-333
CO_2e emissions saved (tons)	97,000
Water use avoided (gallons)	41,000
Land use prevented (acres)	3,200

BUSINESS CASE: MATERIALS INNOVATION LAB

DESCRIPTION

The Charlotte Materials Innovation Lab (MIL) is a concept for a university-affiliated student-startup incubator program focused on new value propositions around organic waste fractions. The aim is to reduce the total amount of organic waste by generating and supporting innovative local initiatives for high-value upcycling of specific organic waste fractions.

In the past few years, the number of startups using organic waste streams to produce new products or resources has exploded, and Charlotte can tap into this trend by stimulating the entrepreneurial spirit of the city. Because such Food Tech initiatives often require a lot of upfront research and innovation, we propose that the city establish a centralized Materials Innovation Lab that would have all the equipment needed for experimentation and testing, potentially located at The Innovation Barn development.

There are two stakeholders that will be crucial to success. Firstly, the Charlotte MIL would require a strong partnership with one or more nearby universities, as the MIL is meant to support student entrepreneurs in the city, and professors and teachers can provide entrepreneurs with technical guidance during the product development phase. Secondly, a consortium of organisations that have an interest in organic waste would be required to partly fund the program, and provide the startups with the necessary networks, expertise and commercial feedback.

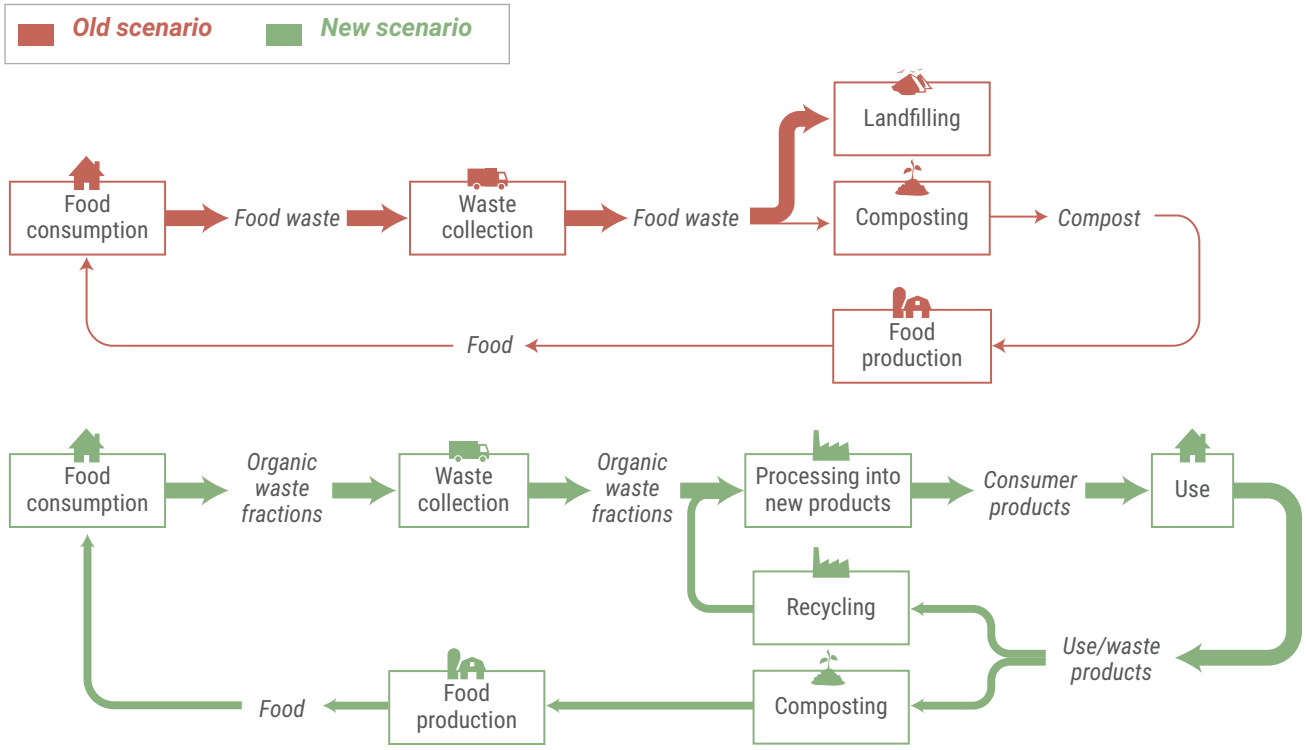


Figure 11. Overview of the Materials Innovation Lab Case

EXAMPLE CASES

The Erasmus Centre for Entrepreneurship is a not-for-profit incubator that helps student entrepreneurs during the validation phase of their business idea. Startups are guided through a multi-week accelerator program and given access to a network of industry players and investors. They have multiple running programs, including specialized tracks focused on key sectors of the Rotterdam economy. Apart from the incubation programs, ECE also organises executive education programs, MBAs focused on entrepreneurship, and other events.

Key stats

- *Over a hundred budding entrepreneurs start their company each year through the program*
- *Has a pool of around 60 academic and industry experts available for coaching and mentorship, as well as close ties to commercial businesses*

Fruitleather Rotterdam produces leather-like material from fruit waste. Though still in the startup and product development phase, they provide a good example of the type of startup that could be housed in the MIL. Due to the high costs of production, their clients are limited to high-end luxury fashion brands, though they expect to be able to compete with real leather. Their main supplier is the harbour of Rotterdam, which is able to supply them with millions of kilograms of fruit waste.

Key stats

- *For every square meter (about 10 ft^2) of 'leather' they produce, they require around six kilograms of fruit puree*
- *The price per square meter is currently around €400, but they hope to reduce the costs to compete with real leather*
- *They can process 1000 kg of fruit an hour*

Ecor is a biobased material that serves as an alternative to particle board, cardboard, and other materials. The company was founded in 2014 as a partnership between the company Noble Environmental Technologies and the United States Department of Agriculture. The material is made from cellulosic wastes including cardboard, newspaper, and agricultural fiber, only requiring the addition of heat and water for its production.

Key stats

- *ECOR's can convert 1,250 tons of wastes per year, with another 37,500 ton capacity planned for new facilities*
- *Wastes cost $0-236/ton, Panels sells for $1,700/ton*
- *Together, the four facilities will prevent the use of over 600,000 trees and 112,500 yd3/year*

Venn Reactor based in Hong Kong, is an innovation supply-chain accelerator that provides research, design, engineering, and sourcing to global premium brands. Venn Reactor specializes in the design-to-manufacture of specialty products that combine hard materials (plastic, metals, meshes), soft materials (textiles, vinyl, or leather), and smart digital systems.

Key stats

- *One of their most innovative products is a moldable plastic-like material that is made of a combination of orange peel and cornstarch epoxy which is suitable for making lamps, phone cases, etc.*

CONTEXTUAL ASPECTS

The main potential barriers to implementation of a materials innovation lab in Charlotte include developing the right partnerships (with universities and the private sector), securing funding, and motivating students to take part in an incubator program. For this last issue, we have heard that it is difficult to get students engaged in Charlotte, even in entrepreneurial activities, so the program has to be attractive to participate in. To make sure this barrier is overcome, the innovation lab could introduce competition for participation in the incubator with awards and other recognition for entrepreneurial students.

UNC Charlotte is already planning to participate in the Innovation Barn project and could be a key partner for the program, though ideally the incubator program would include partners and students from other universities and colleges of Charlotte to encourage multi-disciplinary entrepreneurship in the circular economy.

IMPLEMENTATION IN CHARLOTTE

The Charlotte MIL could be based on the model of ECE in Rotterdam. With a rolling accelerator program of around 15 teams, with on average 1-2 founders per team, the facility would require at least 1,000ft^2 of office space, and preferably more for product prototyping. Space at the Innovation Barn is provided by the city for a period of five years after completion, though on the long term it can be expected that continued use of the space will require rent of an estimated $0-$28,800/year for the use of 1,600 ft^2. Utility costs are estimated at around $2,720/year.

One of the most important resources that the MIL can offer budding entrepreneurs is availability to the necessary tools and machinery for developing their product. At the very least, such a lab would include a fruit pulping machine, automatic composting machine, and organic waste de-watering screw press, which together would cost an expected $20,000-30,000 dollars. Furnishing the space with desks as well as basic prototyping equipment would require an additional investment of around .

Operationally, the program would need at least two full time staff, as well as a pool of around 15-20 academic and industry experts to guide the student entrepreneurs. The initiative will require collaboration between many stakeholders. The most important are the university, including the professors, academics, and teaching assistants who will assist in the Lab's incubator program, the local student community, and businesses and industry experts who will provide the startups with market feedback. ECE Rotterdam offers dedicated validation programs that help set up programs like this, and Charlotte could potentially partner with them for the MIL.

Altogether, setting up the university-affiliated Charlotte Materials Innovation Lab would require an initial investment of around $61,000, and an annual budget of around $218,000 to cover salaries, marketing, and overheads, and optionally $600,000 in annual seed investments for the approximately 60 startups. Given that the incubation center will be affiliated with local universities, we expect most of the funding to come from the university itself. However, the MIL could be partly funded through corporate sponsorships of the incubation program, or executive training programs. Most accelerator programs take a small equity stake in the participating startups in exchange for guidance and a small seed investment.

Table 5: Materials Innovation Lab Costs and Benefits

COST	VALUE
Investment costs	$61,000
Rent	$0 - $28,800
Personnel	$180,000
Fuel and utilities	$2,720
Annual Seed Investments	$600,000
Total	$61,000 investment + $182,700 - $217,280

REVENUE	VALUE
Revenue from shares	$214,286 (in year 3)
Other revenue*	$69,000
Total	$283,286
Return on investment	N/A
Payback period	N/A

**Assumed additional revenues from events, conferences, and executive trainings*

OPPORTUNITIES

In the end, 90% of startups fail, and this is unlikely to be any different for the Charlotte MIL. Nevertheless, even if just 10% of the startups that enroll in the program achieve commercial success, that would mean six new companies per year would be successful, creating an average of 14 - 21 new jobs directly every year (Empson, 2012).

While most of these would likely be smaller niche companies like FruitLeather (each diverting around 7 tons of waste per year), the occasional scalable business, like Ecor (diverting 1,250 tons/year) could add much more significantly to the waste diversion potential. If we assume one out of ten successful business is scalable, then overall this incubator could result in a diversion potential of around 1,285 tons/year (accumulating each year as more companies find success).

Over a ten year period, this would account for a share of around 1.4% of the total waste to landfill and a CO2e emissions reduction potential of 23,000 tons over the period. The main benefit of the Materials Innovation Lab is less direct - education of students in a practical way through experience with entrepreneurship, new innovations and patents in Charlotte, indirect employment through activities adjacent to the work start-ups are doing, attractiveness of Charlotte to STEM students and graduates, etc.

It will be hard for the MIL to be financially sustainable. We expect the program to require significant funding in the first few years of its existence, and our estimates indicate that the returns on its seed investments will be relatively low. However, there are a number of other revenue models that the MIL can adopt to supplement this income, such as executive training programs or hosting events, which we believe could bring in another $69,000 per year. It is likely that the university will need to fund the remaining budget. However, we believe the indirect benefits to both the university and the city makes this a good investment.

Table 6: Materials Innovation Lab Opportunities

OPPORTUNITY	VALUE
Total waste diverted from landfill (lbs/year)	2.57 million lbs/year
Potential profits from case ($/year)	N/A
Total jobs created (#)	14-21 jobs/year
CO_2e emissions saved (tons)	23,000 tons over ten-year period
Water use avoided (gallons)	Dependent on products produced
Land use prevented (acres)	Dependent on products produced

BUSINESS CASE: INCENTIVIZED REVERSE LOGISTICS SYSTEM FOR MATERIALS

DESCRIPTION

One of the largest problems we need to address for achieving circularity in Charlotte is handling the low recycling participation rates, and even those who do participate are not separating all of their recyclables. For example, we estimate that just over 2% of plastics coming from households are recycled. At the same time, a second problem in the city is that the quality of the recyclables currently produced is not high enough for recyclers in the region (too contaminated and mixed with other materials). We would like to address both of these problems simultaneously through an "incentivized reverse logistics system".

To ensure that recycling participation increases, citizens should be incentivized to participate in recycling, even in the absence of a state deposit system. While there are other options possible that have proven successful (such as pay-as-you-throw programs), there is a lot of political resistance to increasing costs for waste management, and rightly so, as these tend to increase the burden disproportionately for low-income households. An alternative that has been suggested is an "untax" system, where households are rewarded for good behavior, rather than being taxed for not recycling.

The Charlotte incentivized reverse logistics system is a new model we propose for recovering different recyclables in the city. The idea is that citizens are incentivized to recycle by receiving tokens for recyclables that they can exchange at local stores for discounts on or free products or services. The waste streams that are collected are cleaned and processed and then sold on to recycling firms. Eventually, we envision a fully automated take-back system that utilizes the existing return logistics infrastructure of for instance supermarkets. This would also improve the efficiency of collection and recycling.

There are many plastics brokers that could use this model to affordably increase their revenues, although it may be more feasible to set up new organization. Establishing an incentivized reverse logistics system will require significant up-front investment. WASTED Lab, a non-profit in Amsterdam which has set up a system that partially resembles the idea proposed for Charlotte, is mostly funded by the municipality of Amsterdam and support from the city will likely be required to establish the system at the start. However, we believe that with the right partnerships and infrastructure a sustainable business model can be built so that the revenues from the sale of recyclables can cover the costs of logistics and pre-processing.

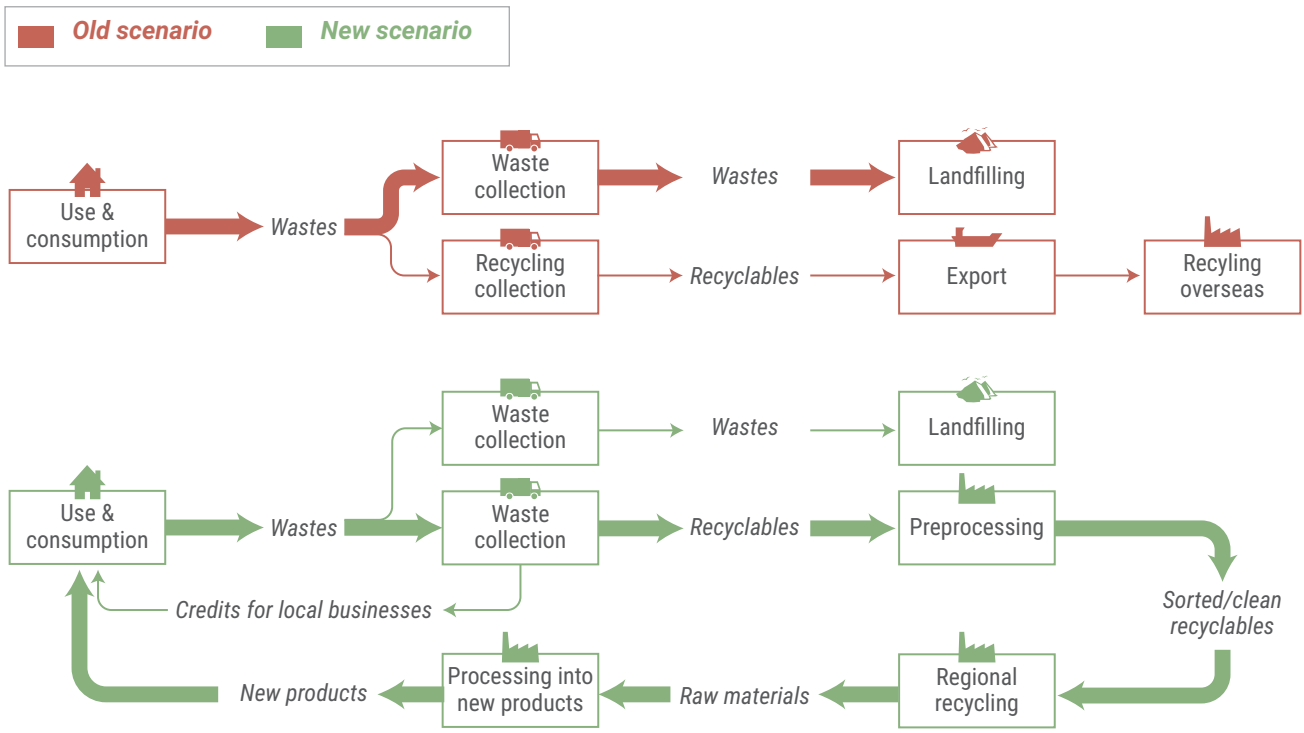


Figure 12. Overview of the Incentivized Reverse Logistics Case

EXAMPLE CASES

RePlanet is a recycling center operator in California that provides the option for getting money back (or donating the money to charities) for bringing clean and dry recyclables. Recyclable materials can be traded in either in staffed centers (payment per pound) or through Automated Recycling Machines (ARM). The recyclables are exchanged for vouchers which customers can deduct from their grocery bill or which they can redeem for cash. Alternatively, the value of the vouchers can be donated to a cause of the person's choice.

Key stats

- *RePlanet Automated Recycling Machines (ARM) are available in nearly all major grocery chains*
- *Locals can return aluminum and bimetal cans, glass bottles, and #1-#7 plastic bottles (only)*
- *Payments range between 10.5 cents per pound (glass bottles) to $5.62 (#6 PS plastic bottles)*

WASTED Based in a neighborhood of Amsterdam established a waste collection program, starting with plastics and then branching out to textiles, glass, and paper. While the Netherlands has a deposit system in place for some glass and plastic bottles, the incentive for recycling other materials was low, which led this organization to develop an incentive program for other materials. Participants bring a bag of recyclables to local collection points, scan a QR code sticker and send a picture of the bag, and receive a digital currency (one "coin" per bag of recyclables). The digital currency can be used in local businesses for discounts and free products. The organization's incentive program employs four people and has a budget of €150.000.

Key stats

- *WASTED has 1,700 participants - almost 5% of the neighborhood's population*
- *The program has 86 rewards (from 57 businesses) available for tokens, including discounts on groceries and flooring, buy-one-get-one-free beers and movie tickets, and free massages and coffee tasting workshops*
- *WASTED has collected over 5,391 kgs of plastic since April 2015, and 5,862 kgs of glass, 3,770 kgs of paper, and 1,827 kgs of textiles since June 2017*

CONTEXTUAL ASPECTS

In order to successfully implement a program for incentivized reverse logistics, the main challenges are economic (ensuring a good business case for recyclers and local businesses) and logistical (decentralized collection and centralized pre-processing of recyclables), though some social challenges also exist in getting the right type of traction and participants in Charlotte.

For regional recyclers to support this type of system and purchase recyclable materials through it, the materials would need to be relatively clean and free of other materials. High rates of contamination (+30%) are currently quite common. By putting stricter requirements on the recyclables delivered to the program by households and by separating materials, the quality should be higher. As an incentive system allows for tracking bags back to participants, failure to deliver the right quality of recyclables can be addressed by reaching out directly to individual participants.

Logistically, the best option over the longer term is to install reverse vending machines in commonly visited shopping areas (such as grocery store parking lots), which will automatically measure and sort materials which can be collected in central locations. This option makes it easiest for households to participate in such a program. However, in the shorter term, when participation rates are lower, it will likely be more feasible to collect from individual households or central points in neighborhoods (such as community centers).

One of the main social barriers for this program is ensuring the system provides the right type of incentives for participation from low-incomes households and households who are not already recycling. Partnerships with the right types of local businesses and marketing the program through the proper channels is key to mitigating the risk of mostly attracting participants that are the usual environmentally-conscious crowd (as experienced with the WASTED program in Amsterdam).

IMPLEMENTATION IN CHARLOTTE

The first step towards implementation is establishing the incentive program for recyclables, which involves creating an app for the program, designing a tracking method, and establishing partnerships with local companies who want to take part in the program. A small team of around four employees will be necessary to design the program, form partnerships, and handle marketing. In addition to the personnel costs, the incentive program will also require a marketing budget, funds for plastic bags and stickers (for example QR code stickers), and other overhead costs.

The overall cost of the incentive program is estimated at around $164,000/year, which is similar to the funding requirements of the WASTED program in Amsterdam. Over the longer term, as the program finds more success, these overhead costs may double as a larger team is necessary to service a higher number of participants and business partners. Ideally the funding would come originally from the city (to be compensated by lower costs from tipping fees for landfilling), though if the program expands it could operate self-sufficiently from the revenues of material sales.

Over the short-term, we assume that 5% of the households in Charlotte will become participants in the incentive program, recycling 10% of their recyclable paper, textiles, glass, and plastics. These will be brought to local neighborhood collection points and taken to a central facility for sorting, baling, and selling.

Table 7: Incentivized Recycling Costs and Benefits

COST	VALUE
Investment costs	ST: $1.7 mln, LT: $12.6 mln
Rent	-
Personnel	ST: $565,000, LT: $2.1 mln
Other overhead costs	ST: $142,000, LT: $724,000
Payments to 3rd parties	-
Total	ST: $1.7 mln investment + $707,000/yearly, LT: $12.6 mln investment + $2.8 mln yearly

REVENUE	VALUE
Revenue from product sales	ST: $240,391 - $589,821, LT: $5,805,550 - $14,305,480
Total	ST: $240,391 - $589,821, LT: $5,805,550 - $14,305,480
Return on investment	ST: N/A, LT: 24% after year 5
Payback period	ST: N/A, LT: 10.9 years

**ST is short-term, LT is long term*

As the program requires source separation and the volumes would be small in the beginning (~1,810 tons/year), relatively small investments in equipment would be necessary (e.g. a truck for collection, balers, conveyor belts) and feasible with only hand sorting and processing. Including the purchase of a warehouse capable of storing a week's worth of recyclables, the total investment costs would be around $1.7 million. Personnel and other overhead costs would be around $543,000/year (excluding the incentive program).

On the longer term, if the program scales up to around 50% participation, with participants recycling around 25% of their recyclable material, the total mass recycled would reach 44,100 tons/year. In this case, a larger facility would be necessary, along with automated sorting equipment such as optical sorting machines. For logistics, it would make sense to invest in automated recycling machines (ARM), which could be located at grocery stores (we assume around 50 locations in the city).

In this maximum scenario, the investment costs would reach $12.6 million. The yearly operational costs for the program would be around $328,000 and $2.5 million for the logistics, storage, and processing operations.

OPPORTUNITIES

In the short-term scenario (with 5% participation and 10% recycling), the incentive and recycling program can only deliver a revenue stream of around $240,000 - $590,000 and cannot yet function self-sufficiently. However, it should be noted that this scenario results in a reduction of landfill tipping fees of around $55,000 and much of the cost of the program (logistics, processing) replaces existing costs for the same in the current waste system.

The break-even point for profitability is at around a 10% participation rate or a 5% participation rate with high recycling rates (20% of recyclable paper, plastic, glass, and textiles). It may be possible to create an even lower break-even point if good partnerships can be established with recyclers who are willing to pay more for material with lower contamination rates. Another possibility is to carefully model which materials should be accepted in the program to provide the best scenario. For example, glass is heavy and expensive for logistics, but also very low value. Which materials are accepted could be determined by which favorable partnerships can be established.

If the ambitious, long-term scenario can be achieved, then the financial benefits are quite high: around $5.8 - $14.3 million in revenues for material sales versus around $2.8 million in costs. This is in addition to the savings from landfilling tipping fees ($1.3 million). If the program reaches this scale, it could make sense to offer direct financial incentives to participants households for recycling, instead of only coupons for local businesses.

In addition to direct financial benefits and employment through the program (35-130 new jobs), regional recyclers would be able to scale up operations. For example, a local HDPE recycler (Engineered Recycling Company, LLC) estimated they would be able to scale up recycling by 30% with existing equipment and space (which is more than even the long-term scenario would produce) by adding personnel, and they currently have too little recycled material to meet the full demand.

Finally, by increasing the amount of material recycled (reducing demand for virgin inputs), this program could have a considerable indirect effect on the embodied impacts of material consumption.

Table 8: Incentivized Recycling Opportunities

OPPORTUNITY	VALUE *
Total waste diverted from landfill (lbs/year)	ST: 3.6 mln lbs, LT: 88.2 mln lbs
Potential profits from case ($/year)	ST: N/A, LT: min. 3 mln per year
Total jobs created (#)	ST: 35, LT: 130
CO_2e emissions saved (tons)	ST: 10,310, LT: 237,003
Water use avoided (gallons)	ST: 675 mln gallons, LT: 18 bln gallons
Land use prevented (acres)	ST: 1,317 acres, LT: 34,404 acres

**ST is short-term, LT is long term*

BUSINESS CASE: CONCRETE RECYCLING CHAIN

DESCRIPTION

Charlotte is a fast-growing city and its stock of building materials is growing along with it. Currently, around 12,000 new apartments are being built in the city (Portillo, 2017) and the construction sector is responsible for more than 55,000 jobs in Charlotte (over 5% of employment). At the end of life, buildings are demolished to make way for new buildings, resulting in one of our largest waste streams. Overall, building materials are responsible for around 30% of all material use (OECD, 2015) and 10-15% of all waste streams (Modak, 2011).

One of the main building materials is concrete, accounting for around 70% of all building waste materials (Statista, 2014). In Charlotte, much of the concrete waste from demolition is crushed and downcycled to lower value uses (e.g. as backfill). Even so, around 50,000 tons of concrete ends up in landfill each year, accounting for 6% of the total mass that goes to landfill, representing a loss in terms of economic value and resulting in increased impacts.

Concrete is made of 15-20% water, 60-75% aggregate (e.g. sand, gravel), and 10-15% cement. Concrete is a highly impactful material accounting for 5% of CO_2e emissions globally (Crow, 2008), mainly due to the cement in the mixture. Due to the high impacts of this material, cement recycling should be a top priority. Even the sand in concrete may be a key resource to prioritize recycling locally, as recent sand shortages in certain parts of the world (Torres et al., 2017) remind us that due to the high costs of transportation, sand is mostly a local (not global) resource. This aspect of transportation is also an important issue economically, as it is expensive to transport such a heavy material over long distances.

We propose establishing ambitious targets and a supply chain around concrete recycling to guarantee that 100% of concrete removed during demolition makes its way back into new concrete. Additionally, other waste materials (namely glass) can also be recycled into new concrete. While this business case requires changes at every step of the building life cycle, ensuring that no concrete ends up in the landfill can reduce tipping fees and transportation costs in addition to making large impact reductions.

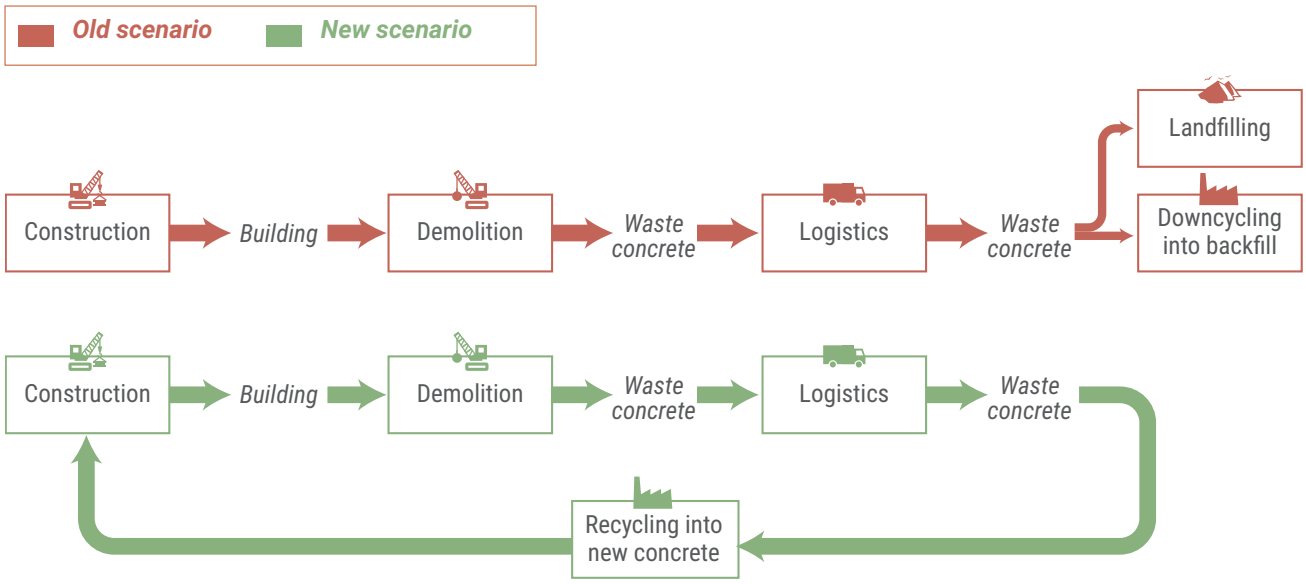


Figure 13. Overview of the Concrete Recycling Chain Case

EXAMPLE CASES

The **"Beton Akkoord"** or concrete agreement is a joint initiative between public and private parties in the Netherlands to make the concrete chain more sustainable through innovation, knowledge sharing, and collaboration. To date, more than fifty construction companies have signed the agreement. The goals are to reduce CO_2e emissions, support biodiversity and society, and promote circularity.

Key stats

- *The program aims for 100% recovery of all concrete waste material in the chain and 100% reuse of reusable concrete components*
- *Design for reusable components is a major cornerstone of the agreement*

The **Cement Sustainability Initiative (CSI)** is a global effort by cement companies to enable sustainable development. One of their goals is to raise awareness of concrete recycling to increase the rates of recovery. The initiative suggests that government and stakeholders increase data transparency on demolition waste, develop economic incentives and legislation to encourage concrete recycling, and set targets for recycled concrete use.

Key stats

- *24 major cement producers active in more than 100 countries are participants*
- *Collectively, these companies account for 30% of global cement production*

Cherry Companies is a recycling and demolition company headquartered in Houston, which recycles different construction materials including concrete (which can be used in ready-mix concrete). Recycled concrete and asphalt materials are used primarily in road and highway projects.

Key stats

- *The company recycles more than 2 million tons of concrete and asphalt every year.*
- *The company produces 99.6% recycled materials*

CONTEXTUAL ASPECTS

The main barriers to realizing a circular concrete chain are related to the physical infrastructure and storage capacity of Charlotte to handle concrete recycling. While technologies exist to recycle concrete into new concrete on-site, it is not always the case that demolition and construction happen simultaneously. This means that storage capacity for demolition wastes should be established, but the heavy weight of these types of materials means that storage and processing should be located near the construction and demolition sites. Combined with the intermittency of supply and demand of recycled concrete, this poses a major logistical challenge.

One possibility is the establishment of temporary decentralized material hubs. Identifying suitable locations for these sites requires knowledge on when materials will become available or be in demand. Thus, a prerequisite for implementation is urban mining maps, which can be used to optimize for temporary hub locations. This is a valuable exercise to enable optimal reuse of other building materials, and material hubs can be used to store other types of materials beyond concrete from demolition projects.

An additional barrier to concrete recycling is the common misconception that recycled materials are lower quality than virgin materials. In many countries, there are limits on the maximum amount of recycled aggregates that can be used in new concrete, for example 20% in the UK, Switzerland, and the Netherlands (MPA, 2013; Kuosa, 2012; McNeil, et. al., 2013). 20% recycled aggregate will likely be the maximum attainable share in the short-term and this will only be attainable with education for aggregate and concrete producers on the quality and benefits of recycled materials.

Finally, as Charlotte already has access to nearby sources of virgin concrete aggregate (e.g. from the Martin Marietta quarries in Charlotte), this may be a barrier to incentivizing local concrete recycling. Offering tax credits for the use of recycled aggregates over virgin materials or providing some other financial incentive may be necessary to encourage selection of recycled concrete.

IMPLEMENTATION IN CHARLOTTE

To implement this business case in Charlotte would require demolition companies or haulers, C&D waste processing companies, and concrete producers to work together, but there are clear benefits to each of these parties in concrete and glass recycling. Haulers would need to take concrete to a recycler (instead of a landfill), but this saves them costs in tipping fees. A C&D recycler would need to process waste concrete and glass into inputs for new concrete, though it could provide them with a nice new revenue stream. Concrete producers would need to accept recycled materials, but should save significantly in material input costs.

In North Carolina, 18.6 million tons of concrete are produced per year. The estimated share of this produced in Charlotte is around 1.5 million tons per year. If 20% of the aggregate was replaced with recycled concrete and 20% of the cement was replaced with recycled glass, this would mean 212,049 tons of recycled concrete and 38,814 tons of glass could be used to make all of the new concrete produced in Charlotte contain 16.4% recycled material.

Table 9: Concrete Recycling Chain Costs and Benefits

COST	VALUE
Investment costs	$300,000
Rent	-
Personnel	$80,000
Fuel and utilities	$175,604
Glass purchasing	$3.9 million
Total	$300,000 investment + $4.14 mln in yearly costs

REVENUE	VALUE
Revenue from collection	-
Revenue from product sales	$6.14 million
Total	$6.14 million
Return on investment	3,389%
Payback period	1.5 years

In the region of Charlotte there are already companies crushing and recycling concrete into backfill and other uses. One large company doing this is C&M Recycling, who was recycling almost 400,000 tons of concrete in 2006. As these companies already have the equipment for crushing concrete into an appropriate size for use as aggregate, an additional investment would only need to be made for a high-capacity fine glass crusher (around $300,000). Extra personnel to process the additional material would be necessary, which we estimate at less than five FTE/year.

The marginal maintenance and fuel costs are estimated at $0.70/ton, for a total of $175,604. While the input of demolished concrete is considered free (demolition companies or haulers save money by not having to pay $5-$39/ton in tipping fees), sourcing the glass is estimated at a cost of $100/ton. This forms the highest cost at a total of $3.9 million. It should be noted that this is the price for premium packaging glass, and as the county is having difficulty finding a market for recycled glass, the price could be much lower.

While there is a small advantage in terms of a final product made from recycled materials (for example in LEED point qualifications), it is unlikely that concrete producers are going to adopt recycled aggregate and glass in their product unless it also represents a cost benefit. This means that the recycled aggregate needs to have a cost that is lower than the virgin materials. We assume that the crushed glass powder and recycled aggregate can be sold to concrete producers at 80% of the price of virgin materials, which results in a yearly revenue of $6.14 million.

OPPORTUNITIES

Beyond bringing financial benefits to all parties in the concrete recycling chain, this business case can also bring environmental impacts. Recycling all of the concrete currently going to landfill can reduce the total mass to landfill by a considerable 5.3%. Combined with a strategy to increase glass recycling by households (with a potential market for valuable recycling locally), this could reach as high as 8.5%.

In terms of concrete production, the recycled glass powder can reduce CO_2e emissions by 19% and water use by 14% (Jiang et al., 2014). In total, this means savings of almost 42,000 tons of CO_2e and 183 million gallons of water. While the aggregate recycling has a negligible effect on CO_2e emissions, it can reduce the overall land footprint by 30% (Braunschweig et al., 2011).

In addition, this business case alleviates a current problem in finding a suitable market for recycled glass in the Charlotte region. If prices for this material can be lowered, it would prove to be an even more profitable business case.

Table 10: Concrete Recycling Chain Opportunities

OPPORTUNITY	VALUE
Total waste diverted from landfill (lbs/year)	100 million lbs
Potential profits from case ($/year)	$2 million after first year
Total jobs created (#)	5
CO_2e emissions saved (tons)	41,186
Water use avoided (gallons)	183 million
Land use prevented (acres)	Unknown

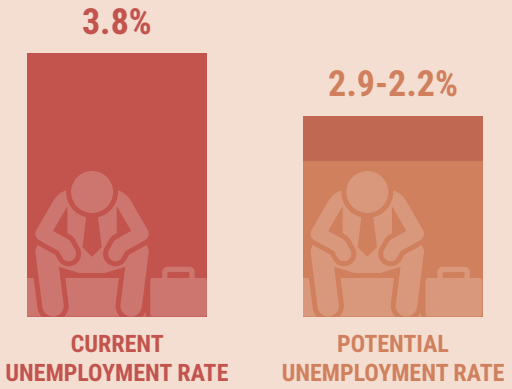
KEY TAKEAWAYS

Together, each of the cases looks promising for Charlotte, athough some are less feasible in the short term than others. For example, the food waste-to-feed production chain may still be hindered by the legal status of feed produced from food waste for the coming period, at least at this scale. The incentivized recycling collection system, while it should be implemented on the short term, will take years to result in the optimal level of participation and impact.

When implemented, the cases can have a significantly positive impact. This includes diverting a large share of the waste currently going to landfill, reducing CO_2e emissions by up to 379,000 tons/year (through reduced landfill and upstream production emissions), making considerable reductions to the embodied land and water footprints from producing virgin materials, and creating new employment opportunities for the city).

Together, the business cases can divert 103,000-145,000 tons from landfill, reducing the total mass by 10.9-15.4%.

The business cases can collectively create 290-492 jobs, reducing the number of unemployed by 24-41%.



Out of the 29 indicators we proposed in Chapter 2 for measuring circularity holistically in the city, each business case improves between 13-19 of the Key Performance Indicators (KPIs). As shown in the following tables, not all of the indicators are addressed with these business cases, however. Some indicators are more structural, for example providing access to high-quality green space in the city or improving information flows on waste materials. While the business cases may have an impact on these indirectly, uch as reducing landfill space required improving land availability for green space, for the most part these will have to be addressed directly.

Other indicators, such as alleviating social inequality, can be addressed with the new business cases, but only if they are established in the right way. Any one of these initiatives can be formulated to provide jobs to people with difficulty accessing the labor market or to provide high-pay work with the opportunity for training, advancement, and a sense of self-determination. However, this also isn't necessarily the case, which is why we have not considered these as impacted in the business cases. More work has to be done to ensure new initiatives advance society as well as the economy and environment. A circular economy, which should value social capital and labor over the value of materials, is a good opportunity for designing supply chains that are good for society. Nevertheless, it also involves a fundamental change in thinking at its core.

Beyond the benefits that each case can bring when implemented separately, combining different cases can result in additional benefits through symbiosis. In particular, establishing a materials innovation lab (which we have framed as based on biobased innovation, but could be expanded to other types of materials) and the incentivized collection system can interact with other initiatives we explored (as well as many more possible cases we did not explore).

Table 11: Effect of cases on "Charlotte as a Zero Waste City" KPIs

CHARLOTTE AS A ZERO WASTE CITY	CIRCULAR TEXTILES	FOOD WASTE TO FEED	MATERIALS INNOVATION LAB	TOKENIZED RECYCLING	CIRCULAR CONCRETE
1. Charlotte terminates all use of landfills by 2040	+	++	+	++	++
2. Charlotte improves its virgin resource efficiency	+	++	+	++	++
3. Charlotte minimizes annual GHG emissions to 2 tons per person by 2050	+	++	+	++	++
4. Charlotte recovers maximum value from waste streams	+	+	+	0	+
5. Charlotte maintains material quality (complexity) of non-biotic resources	+	+	+	+	+
6. Charlotte ensures that nutrients from all biotic wastes are returned to natural cycles	0	+	+	0	0
7. Charlotte reduces its reliance on critical (scarce) materials	0	0	0	+	+
8. Charlotte improves information flows on waste between stakeholders and the City	0	0	0	0	0
9. Circular companies can thrive in Charlotte	+	+	++	+	+

Table 12: Effect of cases on "Charlotte as a Innovative City of the Future" KPIs

CHARLOTTE AS AN INNOVATIVE CITY OF THE FUTURE	CIRCULAR TEXTILES	FOOD WASTE TO FEED	MATERIALS INNOVATION LAB	TOKENIZED RECYCLING	CIRCULAR CONCRETE
1. Charlotte encourages cleantech (impact-reducing technologies) startups	+	+	++	+	+
2. Charlotte is a world leader in developing, testing and scaling new technologies relating to the circular economy	+	+	+	+	+
3. Charlotte encourages innovation in material intensive sectors (manufacturing, logistics, transportation and waste treatment)	0	0	+	0	0
4. Charlotte is a playground for developing and testing innovative circular solutions	+	+	+	+	+
5. Charlotte supports sustainable and circular R&D and innovation	0	0	+	0	0
6. Charlotte supports bottom-up community initiatives on sustainability and circularity	0	0	+	0	0

Table 13: Effect of cases on "Charlotte as a Resilient and Healthy City" KPIs

CHARLOTTE AS A RESILIENT AND HEALTHY CITY	CIRCULAR TEXTILES	FOOD WASTE TO FEED	MATERIALS INNOVATION LAB	TOKENIZED RECYCLING	CIRCULAR CONCRETE
1. Charlotte has clean water and air and a low exposure to pollutants	0	0	0	0	+
2. Charlotte has high quality and extensive green areas	0	0	0	0	0
3. Charlotte provides equal access to green areas for all citizens	0	0	0	0	0
4. Charlotte has resilient systems of provision (food, energy, water, etc.)	+	+	+	+	+
5. Charlotte minimizes flooding risk	0	0	0	0	0
6. Charlotte minimizes the use of toxic substances in industry	0	0	0	0	0
7. Charlotte ensures access to healthy food for all	0	0	0	0	0
8. Charlotte promotes social cohesion and strong communities	0	0	0	+	0

Table 13: Effect of cases on "Charlotte as a City with Opportunities for All" KPIs

CHARLOTTE AS A CITY WITH OPPORTUNITIES FOR ALL	CIRCULAR TEXTILES	FOOD WASTE TO FEED	MATERIALS INNOVATION LAB	TOKENIZED RECYCLING	CIRCULAR CONCRETE
1. Charlotte ensures the unemployed have the right type of training/experience to have meaningful circular jobs	0	0	+	0	0
2. Charlotte ensures employment opportunities for all	+	++	+	++	+
3. Charlotte offers meaningful jobs that are tied to the circular economy	+	++	+	++	+
4. Charlotte has circular jobs that provide opportunities for economic mobility	+	+	+	+	+
5. Charlotte ensures that circular economy strategies are leveraged to alleviate social inequality	0	0	0	0	0
6. Charlotte empowers citizens to reduce material consumption and reuse/recycle their materials and goods	0	0	+	+	0

While all five business cases can offer unique benefits to the city if they are implemented, there are remaining barriers and questions which still need to be addressed to ensure that the businesses can be successful.

One familiar barrier is the willingness of waste producers (households and organizations) to make the effort to recycle materials. While the reverse logistics business case aims to address this by providing an incentive framework for households to take action, there are remaining structural challenges which also need to be tackled.

For example, households need education on the circular economy that is engaging and relevant to them personally. From companies, we have heard that it is often more expensive to implement recycling programs than just to send all waste to landfill, even though recycling should generate profits, while landfilling only results in costs for waste haulers. Perverse incentives like this need to be addressed by ensuring waste companies have sufficient information, access to markets, and support in investing in recycling and logistics infrastructure.

Another common thread is the potential reluctance of some companies to adopt recycled materials as an input to their production processes, even when the price can be lower than with virgin materials. While this can be addressed partially through education, more support may be needed, for example in testing the quality of recycled materials to prove they are suitable and safe, or even by doing new research in development of processing technologies.

Beyond these issues, there are many more structural barriers and issues in Charlotte that need to be addressed to ensure that these business cases and other initiatives in the city can be successful. These business cases can be an excellent starting point for building the right type of capacity, partnerships, and knowledge to take on more ambitious projects in the future, but they cannot stand alone without addressing the underlying issues that result in a linear economy. There is still much work to be done!

CONCLUSIONS AND NEXT STEPS

REFLECTION ON A CIRCULAR CHARLOTTE

The small selection of business cases explored in this report highlights the fact that a Circular Charlotte can bring a lot of direct benefits to the residents of the city. While the direct benefits on employment and landfill reductions are important, the most valuable benefits are less direct: effects on innovation, entrepreneurship, social cohesion, and the resilience of the local economy and community. Circularity is an important way for Charlotte to stand out and cement its position as a leading global city.

However, Charlotte still has a long way to go to become a circular city

In Charlotte, only 11.5% of materials that end up in the waste system each year are recycled or composted. This indicates that Charlotte is currently still a very linear city. While Charlotte aims to achieve ambitious circularity objectives in order to improve the strength and resilience of the city, our assessment reveals that there are still many barriers standing in the way. Without intervention, Charlotte is unlikely to move away from a linear system.

The city must make it convenient and affordable to recycle

One of the main issues that needs to be addressed is simply ensuring that materials make it back into new cycles of use. Charlotte has low recycling participation rates overall and even those who recycle only do so for a small share of materials. The first thing that needs to change is addressing the barriers that prevent households and companies from recycling. Despite the fact that recycling generates revenues while landfilling only represents an additional cost, we have discovered that it is far more expensive and inconvenient for citizens and companies to recycle than to throw materials in the trash.

A pertinent example of this is food waste. Around 16% of all of the waste ending up in the landfill each year is food waste, for which there are no free programs for recycling. For many other materials, such as textiles and electronics, the inconvenience of taking these materials far away by car to have the option to recycle them discourages recycling participation. Textiles alone account for almost 6% of the waste sent to landfill. Policy, economic incentives, and infrastructure will need to be adapted to ensure recycling rates increase.

The city needs to create new products and markets for recyclable materials

In order to increase the materials diverted from landfill, Charlotte needs to create high-value outlets for material cycling at the same time. However, Charlotte's recycled materials have a relatively high contamination rate, which make them difficult to sell for recycling in regional markets, while export is becoming increasingly difficult for the same reason. This threatens the existing recycling system at a time when city wants to shift towards a more circular model.

Previously, baling mixed plastics or paper and selling this on the market was considered a sufficient recycling business model for the city and county. However, to extract significant value from materials and to ensure the city can become circular, new innovations, partnerships, and business models will need to be developed to process specific materials into high-value products that truly bring benefits to the city.

Over the longer-term, more fundamental issues need to be addressed to achieve circularity

While these first issues can be mostly addressed by simply setting into place better infrastructure for collection, separation, and processing of recyclables, over the longer term a shift to circularity requires more fundamental changes. Extending product life cycles for as long as possible, for example through maintenance, repair, and refurbishment, provides the highest societal value. At the end of life of a product, cascading materials into new products that maintain as much complexity as possible is ideal. For example, cotton should be used as cotton again, but when that is no longer possible, the cellulose can be used in paper production.

Oftentimes, this requires a change from the very beginning of the design process, to ensure that products are designed for longevity and can be effectively disassembled into usable parts, components, and materials. This goes far beyond the end-of-pipe solutions of recycling and is an area where Charlotte, as a historical manufacturing hub, can lead the way in developing truly circular products from the start.

Charlotte is already home to innovative initiatives that are paving the way for circularity

Local stakeholders are already undertaking circular initiatives or setting ambitious sustainability or circularity targets. While we highlighted a small number of initiatives we had contact with, there are many more interesting developments taking place, and new ideas brewing among entrepreneurs in Charlotte. What is already happening in Charlotte is inspiring and provides evidence that the motivation and drive to make the city circular already is in place.

The overall vision of these organizations is much larger than what they are currently able to do with the resources they have at hand. One of the main tasks of the city should be to identify how to really upscale these initiatives and bring together different stakeholders to look for symbiotic opportunities. Finally, local awareness of these initiatives should be increased to get more people inspired and involved in supporting the shift towards circularity.

Beyond economic and environmental benefits, a circular Charlotte should also support society

In the current state assessment of Charlotte, we made a rough assessment of the number of jobs associated with recycling materials, which we further worked out in the business cases for specific scenarios. Based on this assessment, we estimated that at least 25% of the currently unemployed people in Charlotte could find jobs in these five new initiatives, even though these only cover around 11-15% of the wastes currently heading to landfill. However, job creation is not the only end goal. These jobs should also be formulated to provide rewarding work with opportunities for personal advancement.

Beyond these business cases, an important part of the overarching circularity strategy should be to provide education and entrepreneurship opportunities for local citizens that support a structural shift to circularity. With these types of activities in place, it will be possible to create meaningful, long-lasting change in Charlotte and to position the city as a frontrunner in circularity and innovation.

NEXT STEPS

In Chapter 4, we presented a strategic roadmap for how Charlotte can take action towards a circular future, focusing primarily on the steps that Charlotte's government can take. Here we summarize some of the most urgent actions and describe what additional steps other stakeholders can take to get involved in the transition.

Key actions local government can take include:

- Taking the lead on improving information flows on waste within the city to provide entrepreneurs and communities with the information they need to evaluate and establish new initiatives
- Measuring and reporting on circularity to identify areas of poor performance for strategic prioritization and to keep the public informed on the progress the city is making
- Identifying and alleviating key local policy barriers to the circular economy (e.g. zoning barriers, waste regulations) and lobbying for state or national policy change to address higher-level barriers
- Establishing stakeholder groups to work together on new cross-sectoral circularity initiatives
- Funding initiatives that will reduce costs for the city over the long term, increase innovation or entrepreneurship, or support underserved communities
- Appoint a Chief Circularity Officer to oversee strategy and track progress towards achieving goals
- Begin discussions on reframing the next interlocal agreement to ensure waste management agreements strongly support circularity

The commercial and industrial sectors can support circularity by:

- Developing comprehensive and ambitious circularity strategies internally and educating and empowering employees to take initiative in making the company more circular
- Establishing procurement protocols that prioritize recycled and low-impact materials
- Designing their own products and processes to ensure that material value can be recovered at the end of life and that the impacts along the entire life cycle of products are minimized
- Taking part in stakeholder discussions with other companies to actively look for industrial symbiosis opportunities
- Setting up internal material reduction and waste recovery processes
- Arranging partnerships with waste management companies who can help them meet ambitious recycling targets

Non-profit organizations can support the community in achieving circularity through:

- Establishing more neighborhood repair hubs to help citizens extend product lifespans and learn repair skills
- Expanding community gardening projects, especially in underserved communities, to empower people to produce their own food
- Setting up open community spaces that function as innovation centers and makerspaces for locals to learn new skills and develop new products
- Providing education on circularity and engaging the community in local recycling initiatives
- Giving support to local entrepreneurs in basic business skills (e.g. website creation, navigating business establishment procedures)

Local funders and financial institutions can create exponential growth in circularity by:

- Establishing revolving funds and microfinancing for initiatives such as green energy, urban farming, small-scale material processing, and refurbishment
- Supporting local accelerators by providing financial advice and investing in promising local start-ups
- Investing in pilot projects for remanufacturing, recycling, or upcycling materials in Charlotte

Educational institutions can structurally support a shift in mindset through:

- Providing comprehensive education on circularity and sustainability at every level
- Making hands-on learning and experimentation accessible to all students, e.g. through 100 Gardens aquaponics, materials innovation labs, or makerspaces
- Increasing student engagement through contests that provide strong incentives for participation by students
- Setting ambitious circularity and sustainability targets internally, examining procurement protocols, and informing and involving students in initiatives

Critical action can be taken by local citizens to increase circularity, such as:

- Reducing their own consumption of single-use and disposable products
- Consciously purchasing goods that will have a longer lifespan, maintaining products, and repairing instead of disposing of them
- Seeking out information about proper recycling and making an effort to recycle as much as possible
- Volunteering with local community organizations to make Charlotte more circular, fair, and healthy
- Petitioning local policymakers and companies to take on ambitious circularity initiatives

BIBLIOGRAPHY

3XN DEPA. (2016). Building A Circular Future, 284. Retrieved from https://issuu.com/3xnarchitects/docs/buildingacircular-future

Abadi, M. (2017, November 28). Forget New York — millennials are flocking to these 11 US cities in droves. Business Insider. Retrieved from https://www.businessinsider.nl/cities-millennials-are-moving-to-2017-11/?international=true&r=US#seattle-washington-2

Alexandra Freitas, Guoping Zhang, & Ruth Mathews. (2017). Water Footprint Assessment of Polyester and viscose. Retrieved from http://waterfootprint.org/media/downloads/WFA_Polyester_and__Viscose_2017.pdf

Alibaba. (2018). Alibaba. Retrieved January 14, 2018, from https://www.alibaba.com/product-detail/Pet-bottle-scrap_50035463485.html?spm=a2700.7724838.2017115.3.72b79e5cU7y3m9

Aluminum Association. (n.d.). Recycling | The Aluminum Association. Retrieved March 28, 2018, from http://www.aluminum.org/industries/production/recycling

American Chemistry Council. (2016). United States National Postconsumer Plastic Bottle Recycling Report. Retrieved from www.plasticsrecycling.org

Antonopoulos, I. S., Karagiannidis, A., & Kalogirou, E. (2010). Estimation of Municipal Solid Waste heating Value in Greece in the Frame of Formulating Appropriate Scenarios on Waste Treatment. Third International Symposium on Energy from Biomass and Waste, (November 2010), 8. https://doi.org/RefwID:62430

Association of Plastic Recyclers. (2018). Plastic Film Recycling FAQs. Retrieved March 26, 2018, from http://www.plasticsrecycling.org/education/faqs/plastic-film-recycling

Auburn Aggregates. (2018). Pricing & Calculator. Retrieved June 19, 2018, from http://auburnagg.com/buy/

Axion Consulting. (2009). A financial assessment of recycling mixed plastics in the UK Financial modelling and assessment of mixed plastics separation and reprocessing on a commercial scale in the UK A financial assessment of recycling mixed plastics in the UK 1. Retrieved from http://www.wrap.org.uk/sites/files/wrap/WRAP A financial assessment of recycling mixed plastics in the UK.pdf

Baker, A. (2015). Fly farming: How it could feed the world | Time. Retrieved June 10, 2018, from http://time.com/3825158/farming-flies-south-africa/

Bakker, M., Hu, M., Nusselder, S., Maqbool, A. S., Deen, R., Blake, G., … Fauzi, R. T. (2015). Closed-loop economy: Case of concrete in the Netherlands. https://doi.org/10.1007/s13398-014-0173-7.2

Bell, N. C., Lee, P., Riley, K., & Slater, S. (2018). TACKLING PROBLEMATIC TEXTILE WASTE STREAMS. Retrieved from http://resyntex.eu/downloads

Bernardo, C. A., Simões, C. L., & Pinto, L. M. C. (2016). Environmental and economic life cycle analysis of plastic waste management options. A review, 10(123), 140001–20053. https://doi.org/10.1063/1.4958429

Block, D. G. (2017, November). 2017: A Mixed Bag for Recycled Plastics Pricing So Far. Plastics Technology. Retrieved from https://www.ptonline.com/articles/2017-a-mixed-bag-for-recycled-plastics-pricing-so-far

Boboltz, S. (2017, December). We Buy An Obscene Amount Of Clothes. Here's What It's Doing To Secondhand Stores. HuffPost. Retrieved from https://www.huffingtonpost.com/2014/11/20/fast-fashion-thrift-stores_n_5798612.html

Brandon Janes. (n.d.). Is recycling glass worth the cost? | News | kdhnews.com. Retrieved March 26, 2018, from http://kdhnews.com/news/is-recycling-glass-worth-the-cost/article_8e2dd0e6-d956-11e2-ab95-0019bb30f31a.html

Bureau of Labor Statistics. (2018). Unemployment Rates for Metropolitan Areas. Retrieved June 6, 2018, from https://www.bls.gov/web/metro/laummtrk.htm

Burwood-Taylor, L. (2017, June). Protix Raises $50m in Largest Insect Farming Investment on Record - AgFunderNews. AGfunder News. Retrieved from https://agfundernews.com/protix-raises-50m-in-largest-insect-farming-investment-on-record.html

Calt, E. A. (2008). Converting Organic Waste to Money 02-07-13, (March), 1–16.

Can Pac Recycling. (2018). Can Pac Recycling. Retrieved January 14, 2018, from http://www.canpacrecycling.com/pricing.html

Canter, L. (2015, July 4). Nappies: which are best – disposables or reusables? | Money | The Guardian. The Guardian. Retrieved from https://www.theguardian.com/money/2015/jul/04/nappies-which-best-disposables-reusables-cost-ethics

Cavalline, T., Assistant, P. E., & Charlotte, U. (2017). Environmental Considerations in Concrete Recycling. Retrieved from http://www.cptechcenter.org/webinars/documents/RCA Environmental Considerations 03-29-2017.pdf

Charlotte Business Journal. (2018). More proof that Charlotte is a boomtown. Retrieved January 14, 2018, from https://www.bizjournals.com/charlotte/news/2015/03/05/more-proof-that-charlotte-is-a-boomtown.html

Charlotte Chamber. (2017). Mecklenburg County Economy Quarterly: A New and Expanded Report 3rd Quarter 2017.

Charlotte Chamber. (2017). Go Green: A guide to Sustainability in Charlotte. Retrieved from https://charlottechamber.com/clientuploads/GreenWorks/Sustainable_Business.pdf

Charlotte Chamber of Commerce. (2015). Charlotte's Major Employers.

Charlotte Fire Department. (2018). About Us > Home. Retrieved June 12, 2018, from http://charlottenc.gov/Fire/about-us/Pages/default.aspx

Charlotte Water. (2018). Charlotte Water Commercial Rates. Retrieved June 20, 2018, from http://charlottenc.gov/Water/Pages/CommercialRates.aspx

Charlottechamber. (2017). International Business. Charlotte NC.

Charlottechamber. (2017). Advanced Manufacturing. Charlotte NC.

Charlottechamber. (2016). Charlotte's Energy Sector: Leading the charge. Charlotte NC.

Charlottechamber. (2017). Information Technology. Charlotte NC.

Charlottechamber. (2015). Charlotte's Manufacturing Industry. Charlotte NC. Retrieved from https://charlottechamber.com/clientuploads/Economic_pdfs/Manufacturers_Directory.pdf

CHARLOTTE-MECKLENBURG POLICE DEPARTMENT. (2018). Our Organization > Home. Retrieved June 12, 2018, from http://charlottenc.gov/cmpd/organization/Pages/default.aspx

Chetty, R., & Hendren, N. (2016). The Impacts of Neighborhoods on Intergenerational Mobility II: County-Level Estimates, (December). https://doi.org/10.3386/w23002

Circle Economy. (2016). Circle Case study, G-Star RAW close the loop denim. Business case and environmental impact analysis, 301–316. https://doi.org/10.1002/dir.10048

City of Austin. (2011). Austin Resource Recovery Master Plan. Austin EcoNetwork. Retrieved from https://austintexas.gov/sites/default/files/files/Trash_and_Recycling/MasterPlan_Final_12.30.pdf

Clark & Chase Reasearch. (2009). Mecklenburg County Residential Recycling Behavior - 2009 Observation Study.

CMC Recycling. (2018). CMC Recycling Burlington. Retrieved January 15, 2018, from https://www.cmcrecyclingburlington.com/current-pricing/

Colvin, P. (2015). 24 Hours Vancouver – Langley bugs turn food waste into feed – Enterra. Retrieved June 10, 2018, from http://www.enterrafeed.com/24-hours-vancouver-langley-bugs-turn-food-waste-into-feed/

Cordell, D., Drangert, J.-O., & White, S. (2009). The story of phosphorus: Global food security and food for thought. Global Environmental Change, 19(2), 292–305. https://doi.org/10.1016/J.GLOENVCHA.2008.10.009

Cotton Incorporated. (2012). Life Cycle Assessment of Cotton Fiber & Fabric, 156. Retrieved from http://cottontoday.cottoninc.com/wp-content/uploads/2014/07/LCA_Full_Report.pdf

Crow, J. M. (2008). The concrete conundrum. Chemistry World, (March), 62–66.

Crozier, T. (2017). CHARLOTTE LODGING OVERVIEW. Retrieved from http://www.cushwakehospitality.com/wp-content/uploads/2017/10/Hospitality_Charlotte-Lodging-Overview_Mar2017_FINAL.pdf

Denison, R. A. (1996). ENVIRONMENTAL LIFE-CYCLE COMPARISONS OF RECYCLING, LANDFILLING, AND INCINERATION: A Review of Recent Studies. Annual Review Energy Environment, 21, 191–237. Retrieved from https://grist.files.wordpress.com/2006/01/1340_denison.pdf

Depken, C. A., & Stephenson, E. F. (2016). Hotel Demand Before, During, and After: Evidence from Charlotte, North Carolina, (September).

DipTerra LLC. (2014). On the Road to Commercial Production of BSFL |Sorting Out the Chaff : The Life and Times of BSF (Black Soldier Flies). Retrieved June 10, 2018, from http://www.dipterra.com/blog.html?entry=on-the-road-to-commercial

DSM Environmental Services Inc. (2017). Utilization Assessment of County Full-Service and Self-Service Waste and Recycling Drop-off Facilities.

Duke Energy Renewables. (2017). Solar Power Projects. Retrieved from https://www.duke-energy.com/our-company/about-us/businesses/renewable-energy/solar-energy

Dunham, J., & Associates. (2016). The Poultry Industry Creates Jobs in North Carolina. Retrieved from http://www.bls.gov/bls/unemployment.htm.

Ecofys. (2017). Circular Economy and Environmental Priorities for Business, 1–23. https://doi.org/10.1038/531435a

Ellen MacArthur Foundation. (2017). A New Textiles Economy: Redesigning Fashion's Future. Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/A-New-Textiles-Economy_Full-Report_Updated_1-12-17.pdf

Empson, R. (2012). Economic Impact Of Startup Accelerators: $1.6B+ Raised, 4,800+ Jobs Created, 2,000 Startups Funded | TechCrunch. Retrieved June 11, 2018, from https://techcrunch.com/2012/11/27/economic-impact-of-startup-accelerators-1-6b-raised-4800-jobs-created-2000-startups-funded/?guccounter=2

Environmental and Energy Study Institute. (2015). Fact Sheet - Jobs in Renewable Energy and Energy Efficiency. Retrieved January 25, 2018, from http://www.eesi.org/papers/view/fact-sheet-jobs-in-renewable-energy-and-energy-efficiency-2015

Envision Charlotte. (2014). The Waste Problem. Retrieved January 15, 2018, from http://envisioncharlotte.com/water-waste-air/waste/

European Commission. (2017). Price development and volume trade of plastic waste EU-28. Retrieved from http://ec.europa.eu/eurostat/documents/342366/351919/web-sheet-plastic.pdf

Fahey, A. (2016). Strong growth in rates, occupancy driving new hotels in Charlotte — CAHA. Retrieved June 1, 2018, from http://www.charlotteareahotels.com/news/2017/1/13/strong-growth-in-rates-occupancy-driving-new-hotels-in-charlotte

Farzana Mohamed, Laura Sandler, Cesar Ramirez, & Jason C. Wong. (1996). Take Back Laws on Industries of the European Community. Retrieved from http://web.mit.edu/course/3/3s32/www/mohamed.html

Foolmaun, R. K., & Ramjeawon, T. (2008). Life Cycle Assessment (LCA) of PET bottles and comparative LCA of three disposal options in Mauritius. International Journal of Environment and Waste Management, 2(1/2), 125. https://doi.org/10.1504/IJEWM.2008.016997

Ford, R. L. (2018). Questions about poultry feed in North Caroline - thomasthorin@metabolic.nl - Metabolic Mail. Retrieved June 8, 2018, from https://mail.google.com/mail/u/0/#inbox/163d5a2fa8239cef

Franklin Associates. (2011). Life Cycle Inventory of 100% Postconsumer HDPE and PET Recycled Resin from Postconsumer Containers and Packaging.

Freeman S. (n.d.). The world is running out of sand — and you'd be surprised how significant that is | Financial Post. Retrieved June 10, 2018, from http://business.financialpost.com/commodities/alarm-bells-ringing-globally-as-world-begins-running-out-of-sand

Gary J. Burtle, Larry Newton, & D. Craig Sheppard. (2012). Black Soldier Fly Prepupae for Aquaculture Diets. Engormix - Aquaculture. Retrieved from https://en.engormix.com/aquaculture/articles/black-soldier-fly-prepupae-aquaculture-diets-t35244.htm

Gary Liss & Associates. (2008). Austin Zero Waste Strategic Plan. Retrieved from https://austintexas.gov/sites/default/files/files/Trash_and_Recycling/Zero_Waste_Plan_-_full_version_-_Council_Adopted_w-resolution.pdf

GaWC. (2017). The World According to GaWC 2016. Retrieved January 8, 2018, from http://www.lboro.ac.uk/gawc/world2016t.html

GBB. (2016). Solid Waste Characterization Study Fall 2015. Charlotte NC.

Gershman, Brickner & Bratton, I. (2007). Strategic Review of Quantities Generated, Processing and Disposal Capacities, and Recycling Market Attributes. Retrieved from www.gbbinc.com

Global Recycling Network. (2018). Global Recyling Network. Retrieved January 14, 2018, from http://www.grn.com/a/view/1206.html

Governing the States and Localities. (2016). Car Ownership in U.S. Cities Data and Map. Retrieved June 6, 2018, from http://www.governing.com/gov-data/car-ownership-numbers-of-vehicles-by-city-map.html

Granger, T. (2009). North Carolina Law to Ban Plastic Bottles from Landfills | ecycler, a new way to recycle online! Retrieved June 6, 2018, from http://ecycler.com/2009/10/05/north-carolina-law-to-ban-plastic-bottles/

GrantThornton. (2018). North Carolina's Top 100 Private Companies, 63–67.

Green Seal Environmental Inc., & Sovereign Consulting Inc. (2015). Construction and Demolition Waste Characterization and Market Analysis.

Hainault, T., Smith, D., Cauchi, D., Thompson, D., Fisher, M., & Hetzel, C. (2001). Recycling Used Electronics - Report on Minnesota's Demonstration Project.

Hanchett, T. W. (2018). THE GROWTH OF CHARLOTTE: A HISTORY. Retrieved May 16, 2018, from http://www.cmhpf.org/educhargrowth.htm

He, K., Tan, Q., Zheng, L., & Li, J. (2018). Adapting to new policy environment – past pattern and future trend in us-sino waste plastic trade flow. International Journal of Sustainable Development & World Ecology, 1–10. https://doi.org/10.1080/13504509.2018.1437845

Henderson, B. (2017). A solar farm may be built on Charlotte's old Statesville Road landfill north of uptown | Charlotte Observer. Retrieved January 23, 2018, from http://www.charlotteobserver.com/news/local/article124113469.html

ICIS (Independent Chemical Information Service). (2015). US east coast R-PET bottle bale prices continue fall. Retrieved January 14, 2018, from https://www.icis.com/resources/news/2015/11/19/9945745/us-east-coast-r-pet-bottle-bale-prices-continue-fall/#

Institute for Local Self-Reliance. (2002). Recycling Means Business. Retrieved January 23, 2018, from https://ilsr.org/recycling-means-business/

Islam, G. M. S., Rahman, M. H., & Kazi, N. (2017). Waste glass powder as partial replacement of cement for sustainable concrete practice. International Journal of Sustainable Built Environment, 6(1), 37–44. https://doi.org/10.1016/J.IJSBE.2016.10.005

Jacopo Prisco. (n.d.). China to U.S.: Please stop sending us your junk - Sep. 11, 2017. Retrieved February 26, 2018, from http://money.cnn.com/2017/09/11/news/china-scrap-ban-us-recycling/index.html

Jiang, M., Chen, X., Rajabipour, F., & Hendrickson, C. T. (2014). Comparative Life Cycle Assessment of Conventional, Glass Powder, and Alkali-Activated Slag Concrete and Mortar. Journal of Infrastructure Systems, 20(4), 04014020. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000211

Jin, R., & Chen, Q. (2015). Investigation of Concrete Recycling in the U.S. Construction Industry. Procedia Engineering, 118, 894–901. https://doi.org/10.1016/j.proeng.2015.08.528

Johnson, V. O., & Jackson, D. (2017). Healthy Communities - SWANA 2017 Excellence Award Entry. Charlotte.

Kelley Stoklosa. (n.d.). New Life for Glass - Recycling Today. Retrieved March 26, 2018, from http://www.recyclingtoday.com/article/rt0112-processing-glass-recycling/

Kim, T., Tae, S., & Chae, C. U. (2016). Analysis of environmental impact for concrete using LCA by varying the recycling

components, the compressive strength and the admixture material mixing. Sustainability (Switzerland), 8(4), 1–14. https://doi.org/10.3390/su8040389

Kinsella, S. (2012). Paperwork : Comparing Recycled to Virgin Paper. Royal Society of Chemistry, 3(April), 1–13. Retrieved from Retrieved from conservatree.org/learn/WhitePaper Why Recycled.pdf.[Accessed on 25 July 2016]

Kuosa, H. (n.d.). Reuse of recycled aggregates and other C&D wastes. Retrieved from https://www.vtt.fi/inf/julkaisut/muut/2012/VTT-R-05984-12.pdf

Kuzhiyil, N., & Kong, S.-C. (2009). Energy Recovery from Waste Plastics by Using Blends of Biodiesel and Polystyrene in Diesel Engines. Energy & Fuels, 23(6), 3246–3253. https://doi.org/10.1021/ef801110j

Leung, V. (2018). News Release – Enterra receives new approvals to sell sustainable insect ingredients for animal feed in USA, Canada and EU – Enterra. Retrieved June 7, 2018, from http://www.enterrafeed.com/news-release-enterra-receives-new-approvals-to-sell-sustainable-insect-ingredients-for-animal-feed-in-usa-canada-and-eu/

Leung, V. (2016, July). News Release – New insect protein gains approval for use in animal feed – Enterra. Enterra. Retrieved from http://www.enterrafeed.com/news-release-new-insect-protein-gains-approval-for-use-in-animal-feed/

Mae Israel. (n.d.). Why you can't toss these into your recycling bin | UNC Charlotte Urban Institute. Retrieved April 10, 2018, from https://ui.uncc.edu/story/why-you-cant-toss-these-your-recycling-bin

Manfredi, S., Tonini, D., Christensen, T. H., & Scharff, H. (2009). Waste Management & Research gases and global warming contributions. Waste Management & Research, (October), 825–836. https://doi.org/10.1177/0734242X09348529

McNeil, K., & Kang, T. H. K. (2013). Recycled Concrete Aggregates: A Review. International Journal of Concrete Structures and Materials, 7(1), 61–69. https://doi.org/10.1007/s40069-013-0032-5

Mecklenburg County. (2018). Construction and Demolition Debris Landfills. Retrieved June 19, 2018, from https://www.mecknc.gov/LUESA/SolidWaste/ConstructionRecycling/Pages/cd.aspx

Mecklenburg County. (2017). Disposal & Recycling Convenience Centers: July 2017-June 2018 Fees & Information, (July 2017).

Michaelbluejay.com. (2017). How much fuel is required to produce electricity. Retrieved January 26, 2018, from http://michaelbluejay.com/electricity/fuel.html

Micks, A. (2012). The Costs of Recycling. Retrieved June 18, 2018, from http://large.stanford.edu/courses/2012/ph240/micks2/

Mid Atlantic Solid Waste Consultants. (2008). Construction and Demolition Debris Composition Study. Mswconsultants, (September), 1–59. https://doi.org/10.1080/1475382862000363139

Miljögiraff. (2016). 75 report LCA on Rec Cotton Miljogiraff HM, (August), 70. https://doi.org/10.13140/RG.2.2.22598.57927

Miller, H. (2012). Dirtytech: They Obsessively Sort and Recycle What You Dump | San Francisco Public Press. Retrieved June 18, 2018, from https://sfpublicpress.org/news/2012-12/dirty-tech-they-obsessively-sort-and-recycle-what-you-dump

Montgomery Scrap Corporation. (2018). Montgomery Scrap Corp Pricing. Retrieved January 14, 2018, from http://www.scrapmsc.com/our-pricing/

Morris, J. (2016). Oregon Recycling Markets Price Cycles and Trends: A Statistical Search for Significant Economic Causes. Retrieved from http://www.oregon.gov/deq/FilterDocs/RecyclingPriceAnalysis.pdf

MPA Cement, & Mineral Products Association. (n.d.). Use of recycled aggregates in concrete. Retrieved from http://cement.mineralproducts.org/documents/FS_6_Use_of_recycled_aggs_in_concrete.pdf

National Asphalt Pavement Association. (2016). Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage.

Neidel, T. L., & Jakobsen, J. B. (2013). Report on initial assessment of relevant recycling technologies. Plastic ZERO - Public Private Cooperations for Avoiding Plastic as a Waste, (September), 1–33.

Nordic Council of Ministers. (2017). Greener Textiles.

Northeast Michigan Council of Governments, Michigan Department of Environmental Quality, Resource Recycling Systems, & Public Sector Consultants. (2016). Recycling in Michigan- Successful Recycling Programs, Best Practices, and Diversion Potential.

OECD. (2015). Material Resources, Productivity and the Environment. https://doi.org/10.1787/9789264190504-en

Office of Planning, & The District Department of the Environment. (2012). Sustainable DC Plan. Retrieved from https://sustainable.dc.gov/sites/default/files/dc/sites/sustainable/page_content/attachments/DCS-008 Report 508.3j.pdf

Paper Recycling Online. (2017). Paper Recycling Online. Retrieved January 14, 2018, from http://www.recycle.cc/freepapr.htm

Parilla, J. (2016). Greater Charlotte in the global economy: Benchmarking the region's global competitive assets. Washington D.C. Retrieved from https://www.slideshare.net/owashburn/greater-charlotte-in-the-global-economy-benchmarking-the-regions-global-competitiveness-assets?ref=https://www.brookings.edu/on-the-record/greater-charlotte-in-the-global-economy-benchmarking-the-regions-global-competi

Patagonia. (2009). Closing the Loop – A Report on Patagonia's Common Threads Garment Recycling Program – The Cleanest Line. Retrieved June 9, 2018, from https://www.patagonia.com/blog/2009/03/closing-the-loop-a-report-on-patagonias-common-threads-garment-recycling-program/

PCA Portand Cement Association. (n.d.). North Carolina Cement Industry, Building the Foundation of North Carolina's Economy. Retrieved from http://www.cement.org/docs/default-source/market-economics-pdfs/cement-industry-by-state/nc-statefacsht-17-d2.pdf?sfvrsn=b78e6bf_2

Pelletier, N. (2008). Environmental performance in the US broiler poultry sector: Life cycle energy use and greenhouse gas, ozone depleting, acidifying and eutrophying emissions. Agricultural Systems, 98(2), 67–73. https://doi.org/10.1016/j.agsy.2008.03.007

Petru, A. (2014, November). What's in Store for Clothes Too Worn to Sell? Triple Pundit. Retrieved from https://www.triplepundit.com/special/sustainable-fashion-2014/thrift-store-happens-donated-clothes/

Pierce, L. M. (2017). How to increase recycling of flexible packaging | Packaging Digest. Retrieved March 21, 2018, from http://www.packagingdigest.com/flexible-packaging/how-to-increase-recycling-of-flexible-packaging-2017-03-15

Plastics Recycling Update. (2016). PetroChem Wire: Recycled HDPE price softens. Retrieved January 14, 2018, from https://resource-recycling.com/plastics/2016/07/19/petrochem-wire-recycled-hdpe-price-softens/

Portillo, E. (2015, May 24). Uptown's hotel building boom: How many rooms are enough? | Charlotte Observer. The Charlotte Observer. Retrieved from http://www.charlotteobserver.com/news/business/biz-columns-blogs/development/article21688650.html

Portillo, E. (2017, May 26). This number shows why developers aren't worried they're building too many apartments in Charlotte. Charlotte Observer. Retrieved from http://www.charlotteobserver.com/news/business/biz-columns-blogs/development/article152694539.html

Premier Recycling. (2018). Mississauga Scrap Metal Pricing. Retrieved January 20, 2018, from http://www.premierrecycling.ca/contact/premier-recycling-mississauga-ltd/pricing/

Protix. (2018). Partners | Protix. Retrieved June 7, 2018, from https://protix.eu/partners/

R.J. Grondin & Sons. (2017). LOADED AGGREGATE PRICING 2017.

Rachel Stone. (n.d.). Charlotte recycling business sees green in discarded e-devices | Charlotte Observer. Retrieved April 6, 2018, from http://www.charlotteobserver.com/news/business/small-business/article82516842.html

Rajiv Joarder. (n.d.). Recycled Glass Price Increases 40% in 3 years - Spend Matters. Retrieved March 26, 2018, from http://spendmatters.com/2015/04/20/recycled-glass-price-increases-40-in-3-years/

RCBC. (2018). Recycling Council of British Columbia. Retrieved January 14, 2018, from https://www.rcbc.ca/resources/faqs/misc1

Recyclebank. (n.d.). Because You Asked: Is Aluminum Foil Recyclable? - Live Green - Recyclebank. Retrieved March 28, 2018, from https://livegreen.recyclebank.com/because-you-asked-is-aluminum-foil-recyclable

Recycler's World. (2018). Recycler's World. Retrieved January 20, 2018, from http://www.recycle.net/

Recycler's World. (2018). Recycler's World. Retrieved January 17, 2018, from http://www.recycle.net/exchange/

RecycleXchange. (2018). RecycleXchange. Retrieved January 24, 2018, from http://www.recyclexchange.com/exchange/

Recycling Today. (2018). Recycling Today. Retrieved January 14, 2018, from http://www.recyclingtoday.com/rmdas/

Recycling Today. (2016). Recycling Today "Off-the-Charts." Retrieved January 14, 2018, from http://www.recyclingtoday.com/article/off-the-charts-september-2016/

Recycling Today. (2014). Recycling Today "Clear Options." Retrieved January 14, 2018, from http://www.recyclingtoday.com/article/rt1114-recycled-glass-commodity/

Resource Recycling. (2013). Growth Trends and New Drivers for Recycling of Non-Bottle Mixed Rigid Plastics. Retrieved from www.resource-recycling.com

RREUSE (The Reuse and Recycling EU Social Enterprises network). (2015). Briefing on job creation potential in the reuse sector. Retrieved from http://www.rreuse.org/wp-content/uploads/Final-briefing-on-reuse-jobs-website-2.pdf

Salmon Business. (2017). Protix seeks new location for expansion of larvae production | SalmonBusiness. Retrieved June 9, 2018, from http://salmonbusiness.com/protix-looking-for-new-location/

Salvage-Exchange. (2018). Salvage-Exchange. Retrieved January 24, 2018, from http://www.salvage-exchange.net/

Scott Mouw. (n.d.). NC State Perspective On Glass Recycling. Retrieved from http://gmic.org/wp-content/uploads/2016/06/2011GOMD-Mouw.pdf

Scrap Register. (2017). United States electronic scrap Prices, China electronic scrap Prices, India electronic scrap Prices. Retrieved January 20, 2018, from https://www.scrapregister.com/metal-price/electronic-scrap/80

Sheets, B. (2014). At recycling center, workers sort 550 tons of trash a day | HeraldNet.com. Retrieved June 18, 2018, from https://www.heraldnet.com/news/at-recycling-center-workers-sort-550-tons-of-trash-a-day/

Shui, S., & Plastina, A. (2013). WORLD APPAREL FIBER CONSUMPTION SURVEY WORLD APPAREL FIBRE CONSUMPTION SURVEY 2013 Effects of the Great Recession on Apparel Fibre Consumption. Retrieved from https://www.icac.org/cotton_info/publications/statistics/world-apparel-survey/FAO-ICAC-Survey-2013-Update-and-2011-Text.pdf

Spend Matters. (2015). Recycled Glass Price Increases 40% in 3 years. Retrieved January 14, 2018, from http://spendmatters.com/2015/04/20/recycled-glass-price-increases-40-in-3-years/

Statista. (n.d.). U.S. cement prices 2017 | Statista. Retrieved June 20, 2018, from https://www.statista.com/statistics/219339/us-prices-of-cement/

Statista. (2014). Share of U.S. construction & demolition waste by material 2014 | Statistic. Retrieved June 12, 2018, from https://www.statista.com/statistics/504126/share-of-construction-demolition-waste-generation-in-us-by-material/

Statista. (2016). Price of sand and gravel United States 2016. Retrieved January 25, 2018, from https://www.statista.com/statistics/219381/sand-and-gravel-prices-in-the-us/

Street, N. T., & Consulting, K. (2012). MECKLENBURG COUNTY NC FOOD WASTE DIVERSION STUDY FINAL REPORT MARCH 2012 Prepared for : Mecklenburg County Solid Waste Waste Reduction / Composting Prepared by : innovative waste solutions, (March).

Swinehart, A. (2014). Is 100% recyclable flexible packaging possible? | Packaging Digest. Retrieved March 21, 2018, from http://www.packagingdigest.com/flexible-packaging/is-100-recyclable-flexible-packaging-possible140807

Tam, V. (2008). Economic comparison of concrete recycling : a case study approach.

Tellus Institute, & Sound Resource Management. (2013). More jobs, less pollution: Growing the Recycling Economy in the U.S. New Economy, 2(3), 157–162. https://doi.org/10.1111/j.1468-0041.1995.tb00074.x

The Balance. (2017). Get Current Scrap Metal Prices in the U.S. Retrieved January 14, 2018, from https://www.thebalance.com/current-scrap-metal-prices-2877937

The Ellen Macarthur Foundation. (2016). The Circular Economy and the Promise of Glass in Concrete. Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/circular-economy/The-Circular-Economy-and-the-Promise-of-Glass-in-Concrete.pdf

The Guardian. (2016). Billions of dirty nappies can be turned into pet litter, insulation and compost. Retrieved January 14, 2018, from https://www.theguardian.com/sustainable-business/2016/sep/06/billions-dirty-nappies-diapers-recycled-pet-litter-insulation-compost-waste-landfill

The Recycling Partnership. (2016). State of Recycling. Retrieved from https://therecyclingpartnership.app.box.com/s/i0wvano7hi3dr3ivqxv689y4zzo583l2

Themelis, N. J., & Mussche, C. (2014). 2014 Energy and Economic Value of Municipal Solid Waste (MSW), Including Non-Recycled plastics (NRP), Currently Landfilled in the Fifty States. Columbia University. Retrieved from http://www.americanchemistry.com/Policy/Energy/Energy-Recovery/2014-Update-of-Potential-for-Energy-Recovery-from-Municipal-Solid-Waste-and-Non-Recycled-Plastics.pdf

Thomas, S. (2018). How Charlotte's massive growth compares to other U.S. metros (SLIDESHOW) - Charlotte Business Journal. Retrieved June 8, 2018, from https://www.bizjournals.com/charlotte/news/2018/03/23/how-charlottes-massive-growth-stacks-up-to-other-u.html

Thompson, P., & Willis, P. (2013). A review of commercial textile fibre recycling technologies A study to identify commercially viable textile fibre recycling technologies, to inform the development of a sustainable market within the UK for recycled fibres, including a high level business case for their operation in the UK. Retrieved from http://www.wrap.org.uk/system/files/private/Commercial textile fibre recycling technoloogies report.pdf

Toby van Vleet. (n.d.). Local recyclers scramble after China curbs recycling imports | Metro. Retrieved February 26, 2018, from https://www.oregonmetro.gov/news/local-recyclers-scramble-after-china-curbs-recycling-imports

Torres, A., Brandt, J., Lear, K., & Liu, J. (2017). A looming tragedy of the sand commons. Science (New York, N.Y.), 357(6355), 970–971. https://doi.org/10.1126/science.aao0503

Tossel, I. (2013). Conversation with David Suzuki leads to maggot-based animal feed - The Globe and Mail. Retrieved June 10, 2018, from https://www.theglobeandmail.com/report-on-business/small-business/startups/conversation-with-david-suzuki-leads-to-maggot-based-animal-feed/article15114182/

Trans-American Trading Co. (2018). Trans-American Trading Co. Recycling. Retrieved January 17, 2018, from http://tranclo.com/sellers/recycling-faqs/

U.S. Census Bureau. (n.d.). North Carolina State Imports. Retrieved from https://www.census.gov/foreign-trade/statistics/state/data/imports/nc.html

U.S. Cluster Mapping. (2018). Regional Dashboard: Cluster Portfolio - Charlotte, NC Economic Area. Retrieved June 9, 2018, from https://clustermapping.us/region/economic/charlotte_gastonia_salisbury_nc_sc/cluster-portfolio#employment

U.S. Environmental Protection Agency (EPA). (2010). U.S. Environmental Protection Agency Office of Resource Conservation and Recovery, (February), 1–70. Retrieved from https://www.epa.gov/sites/production/files/2016-03/documents/warm_v14_containers_packaging_non-durable_goods_materials.pdf

Ulubeyli, S., Kazaz, A., & Arslan, V. (2017). Construction and Demolition Waste Recycling Plants Revisited: Management Issues. Procedia Engineering, 172, 1190–1197. https://doi.org/10.1016/j.proeng.2017.02.139

US EPA. (2018). Resource Conservation and Recovery Act (RCRA) Overview. Retrieved March 28, 2018, from https://www.epa.gov/rcra/resource-conservation-and-recovery-act-rcra-overview

US EPA, OSWER, O. (n.d.). Best Practices for Reducing, Reusing, and Recycling Construction and Demolition Materials. Retrieved June 10, 2018, from https://www.epa.gov/smm/best-practices-reducing-reusing-and-recycling-construction-and-demolition-materials#design

Veldkamp, T., Van Duinkerken, G., Van Huis, A, Lakemond, C. M. M., Ottevanger, E., Bosch, G., & Van Boekel, M. A. J. S. (2012). Wageningen UR Livestock Research Partner in livestock innovations Insects as a sustainable feed ingredient in pig and poultry diets -a feasibility study Title Insects as a sustainable feed ingredient in pig and poultry diets -a feasibility study. Retrieved from http://www.livestockresearch.wur.nl

Velis, C. (2014). A report from the ISWA Task Force on Globalisation and Waste Management Global recycling markets: plastic waste A story for one player – China. Retrieved from https://www.iswa.org/fileadmin/galleries/Task_Forces/TF-GWM_Report_GRM_Plastic_China_LR.pdf

Wang, Y.-S., & Shelomi, M. (2017). Review of Black Soldier Fly (Hermetia illucens) as Animal Feed and Human Food. Foods (Basel, Switzerland), 6(10). https://doi.org/10.3390/foods6100091

Warner, B. (2014, October). The Next Big Thing in the Food Industry: Flies | Inc.com. INC. Magazine. Retrieved from https://www.inc.com/magazine/201406/bernhard-warner/envirofli-ght-turns-black-soldier-fly-larvae-into-food.html

Waste 360. (1993). Reflections On Refuse Collection Management | Waste360. Retrieved June 18, 2018, from http://www.waste360.com/mag/waste_reflections_refuse_collection

Waste 360. (2015). PET, Aluminum Can Prices Drop; Colored HDPE Values Rise in Latest Readings. Retrieved January 14, 2018, from http://www.waste360.com/commodities-pricing/pet-aluminum-can-prices-drop-colored-hdpe-values-rise-latest-readings

Waste Management World. (2017). Dirty Diaper Recycling Project Brings Nappies into the Circular Economy. Retrieved January 14, 2018, from https://waste-management-world.com/a/dirty-diaper-recycling-project-brings-nappies-in-to-the-circular-economy

Watkins, E., Gionfra, S., Schweitzer, J.-P., Pantzar, M., Janssens, C., & Ten Brink, P. (2017). EPR in the EU Plastics Strategy and the Circular Economy: A focus on plastic packaging. Retrieved from https://ieep.eu/uploads/articles/attachments/95369718-a733-473b-aa6b-153c1341f581/EPR and plastics report IEEP 9 Nov 2017 final.pdf?v=63677462324

Watson, D., Charlotte Gylling, A., Andersson, T., Elander, M., & Heikkilä, P. (2017). Textile-to-textile recycling - Ten Nordic Brands that are Leading the Way. Retrieved from http://dx.doi.org/10.6027/

Wikipedia. (2018). Charlotte, North Carolina. Retrieved January 17, 2018, from https://en.wikipedia.org/wiki/Charlotte,_North_Carolina#Demographics

Wipe Out Waste. (2006). Waste Reduction and Recycling Resource Guide- Construction and Demolition, 03, 15–16.

World Population Review. (2018). World Population Review. Retrieved January 17, 2018, from http://worldpopulationreview.com/us-cities/charlotte-population/

World Resources Institute (WRI). (2015). Policy and Action Standard - Waste Sector Guidance, (May).

WRAP. (2012). A review of commercial textile fibre recycling technologies A study to identify commercially viable textile fibre recycling technologies, to inform the development of a sustainable market within the UK for recycled fibres, including a high level business case for their operation in the UK. Retrieved from http://www.wrap.org.uk/system/files/private/Commercial textile fibre recycling technoloogies report.pdf

WRAP. (2017). Market Snapshot - October 2017. Retrieved from http://www.wrap.org.uk/sites/files/wrap/Market Snapshot October 2017_0.pdf

WRAP. (2018). Waste Electrical and Electronic Equipment Collection Guide Robust services in WEEE collection. Retrieved from http://www.wrap.org.uk/sites/files/wrap/WRAP_WEEE_Collection_Guide.pdf

WRAP. (2018). Realising the Reuse Value of Household WEEE. Retrieved from www.wrap.org.uk/eproducts

WRAP, & Green Alliance. (2015). Employment and the circular economy Job creation in a more resource efficient Britain, 28. https://doi.org/10.13140/RG.2.1.1026.5049

Yin, Y., Yao, D., Wang, C., & Wang, Y. (2014). Removal of spandex from nylon/spandex blended fabrics by selective polymer degradation. Textile Research Journal, 84(1), 16–27. https://doi.org/10.1177/0040517513487790

Zamani, B. (2011). Carbon footprint and energy use of textile recycling techniques. Master's Thesis - Chalmer's Institute. Retrieved from http://publications.lib.chalmers.se/records/fulltext/146872.pdf

Slimme puinbreker spaart beton en CO_2 | De Ingenieur. (2018). Retrieved June 10, 2018, from https://www.deingenieur.nl/artikel/slimme-puinbreker-spaart-beton-en-co2

Sand, rarer than one thinks. (2014). Environmental Development, 11, 208–218. https://doi.org/10.1016/J.ENVDEV.2014.04.001

CREDITS

AUTHORS:

Eva Gladek
Erin Kennedy
Thomas Thorin

DESIGN:

Marta Sierra Garcia
Cassie Bjorck

PROJECT MANAGEMENT:

Erin Kennedy, Metabolic
Emily Yates, Envision Charlotte
Victoria Johnson, Charlotte Solid Waste Services

RESEARCH TEAM:

Pieter van Exter
Eva Gladek
El Mehdi El Hailouch
Justin Hoek
Erin Kennedy
Seadna Quigley
Viktoriya Shirochenkova
Tamara Streefland
Fanny Thibault
Thomas Thorin

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Engineered Recycling Company LLC: Dave Dickson
Envision Plastics: Tamsin Ettefagh
Habitat for Humanity ReStore: John Dodson
Johnson C. Smith University: Philip Otienoburu
Goodwill Opportunity Campus: Jason Thomas, Kilby Watson
MakerSpace Charlotte: Steve Gray & Benjamin Gatti
Mecklenburg County: Henry Allison
Next Round Solutions: Margaret Fleeman
O'Leary Group: Robin Turner
Polymers Center of Excellence, Inc: Philip Shoemaker
Pop up Produce: Amanda Zullo & Daniel Heaton
Protix: Kees Aarts
Sealed Air: Chesley Gray Black IV
UNCC: Michael Lizotte
Unifi: Charlie Schwarze
University City Partners: Darlene Heater
Wake Forest University: Dedee Johnston
Wasted: Sietse Gronheid & Francesca Miazzo
Wells Fargo: Curt Radkin & Jeff Austin (former Wells Fargo)

COMISSIONED BY:

CHARLOTTE

ENVISION
CHARLOTTE

METABOLIC

+31 (0) 203690977
info@metabolic.nl
www.metabolic.nl

Meteorenweg 280M
1035RN Amsterdam
The Netherlands