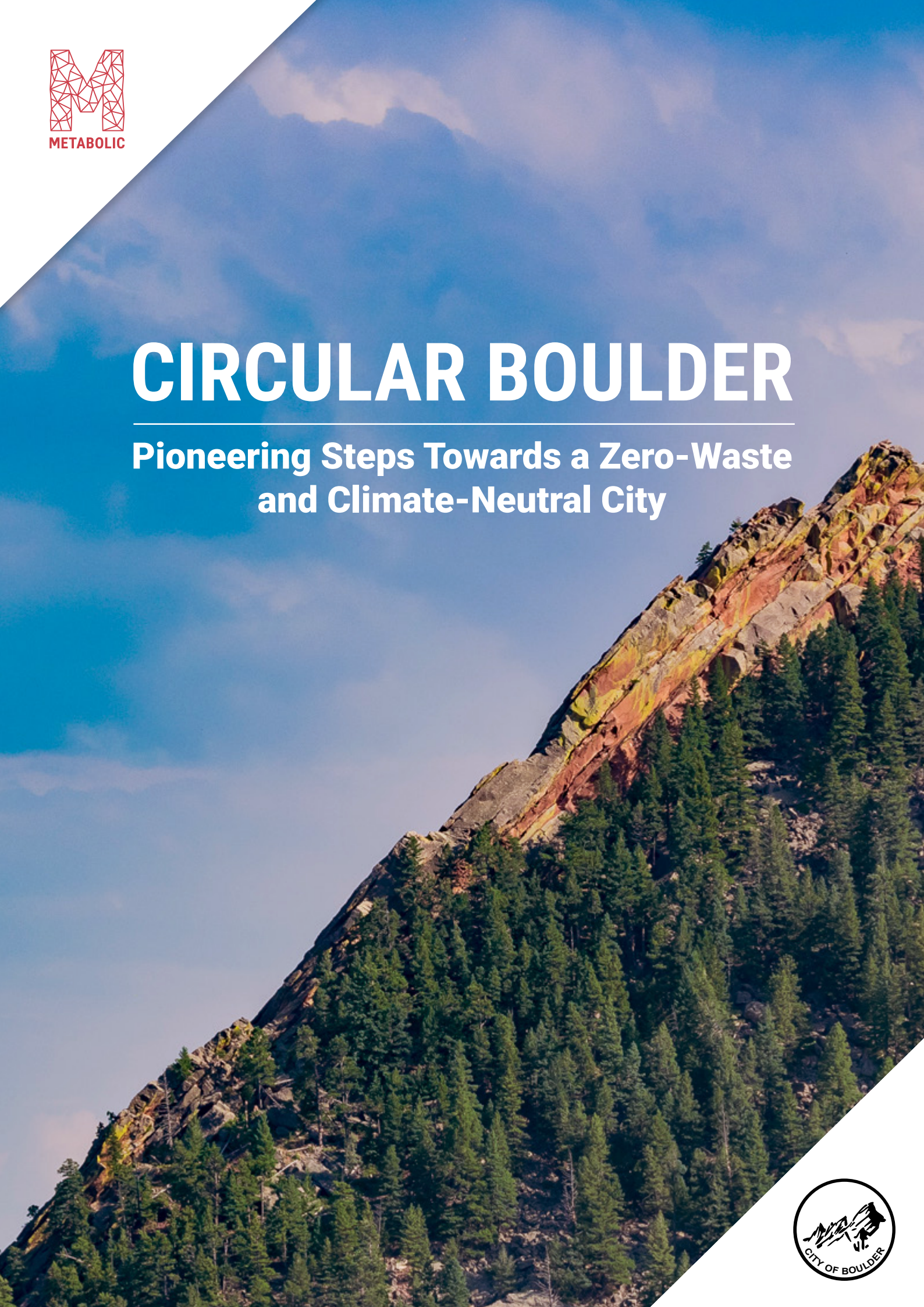
METABOLIC

CIRCULAR BOULDER

Pioneering Steps Towards a Zero-Waste and Climate-Neutral City



CITY OF BOULDER

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01

INTRODUCTION

The city of Boulder has a deep and longstanding connection with the surrounding mountains, from its early history as a mining town, to the present day, where spatial planning processes prioritize mountain views and open space around the city. Boulder's strong outdoor culture and connection to the local environment make sustainability a top concern for locals. Accordingly, the City's Department of Climate Initiatives has been very active on such topics, and in 2017, published an ambitious climate commitment guiding action on three critical areas: energy, ecosystems, and resources.

One of the key goals outlined was an 80% emissions reduction compared to 2005, to be achieved by 2050. Actions the city has already taken towards this goal have resulted in an impressive 16% reduction in greenhouse gas emissions to date, while simultaneously adding jobs and increasing the city's GDP by more than 50% (City of Boulder, 2018) - a promising start to reaching these ambitious targets.

Yet reaching the 2050 goal will require a lot more hard work, and one of the key priorities for accelerating emission reductions is a zero-waste program. Boulder has committed to becoming a "zero-waste" community by 2025, which is defined as reusing, recycling, and composting at least 85% of waste (the remaining 15%, consisting of materials such as medical waste, is considered "unrecoverable"). Additionally, the City is working on strategies to reduce the amount of waste produced per person. By minimizing waste to landfill, emissions from transportation and landfill gases can be prevented.

On the impact scale, Boulder's zero-waste commitment is far more meaningful than addressing the few percent of local emissions caused by waste treatment. Cities are compact consumption centers and most of the environmental impacts caused by urban activity take place outside the borders of the city itself. Especially for a city such as Boulder, which has a strong service economy, the majority of greenhouse gas emissions associated with the choices of local residents is "embodied" in the products and materials imported from outside the city's boundaries. For this reason, some frontrunning cities around the world are exploring "consumption-based" greenhouse gas inventories, in addition to "production-based" ones, which place a local boundary on measuring emissions.

Taking a critical look at consumption of materials and products, in addition to what happens to these when they become waste, represents a major step. This requires a more holistic "life cycle" approach, which is often termed "the circular economy". This summary explains what the circular economy is and describes the current state of circularity in the city of Boulder, looking at material flows through the city and their implications in terms of value and impact. Water and energy are also evaluated at a high level, insofar as they are connected to circularity of materials.

Along with local residents and stakeholders, we have made a start on creating a vision for circularity in the city and outlined some first actions to catalyze and accelerate a circular transition. The foundational elements described here will be taken out to the community to further refine and prioritize the next steps the city should take to create a sustainable and circular Boulder, supporting the current and more ambitious climate goals the city aims to achieve.

02

THE CIRCULAR ECONOMY

Of all the materials we extract globally, only 10% ends up in products. The rest is wasted along the supply chain or dispersed into the environment, before it even reaches the hands of consumers. Even then, 80% of products end up in our waste system within six months, where they have little chance of ever returning to products again (Girling, 2011). Out of all of the materials that leave the global economy each year, only around 10% is recycled into new products, while the rest ends up in an incinerator or landfill (Haas, Krausmann, Wiederhofer & Heinz, 2015).

This type of system is called a **linear economy,** and it is linked to the exacerbation of material scarcity issues, global humanitarian issues related to both material extraction and waste processing, vulnerability to global shocks (lack of resilience and local self sufficiency), and of course the economic and environmental impacts associated with the inefficient loss of products and materials we have invested money, energy, and labor into producing.

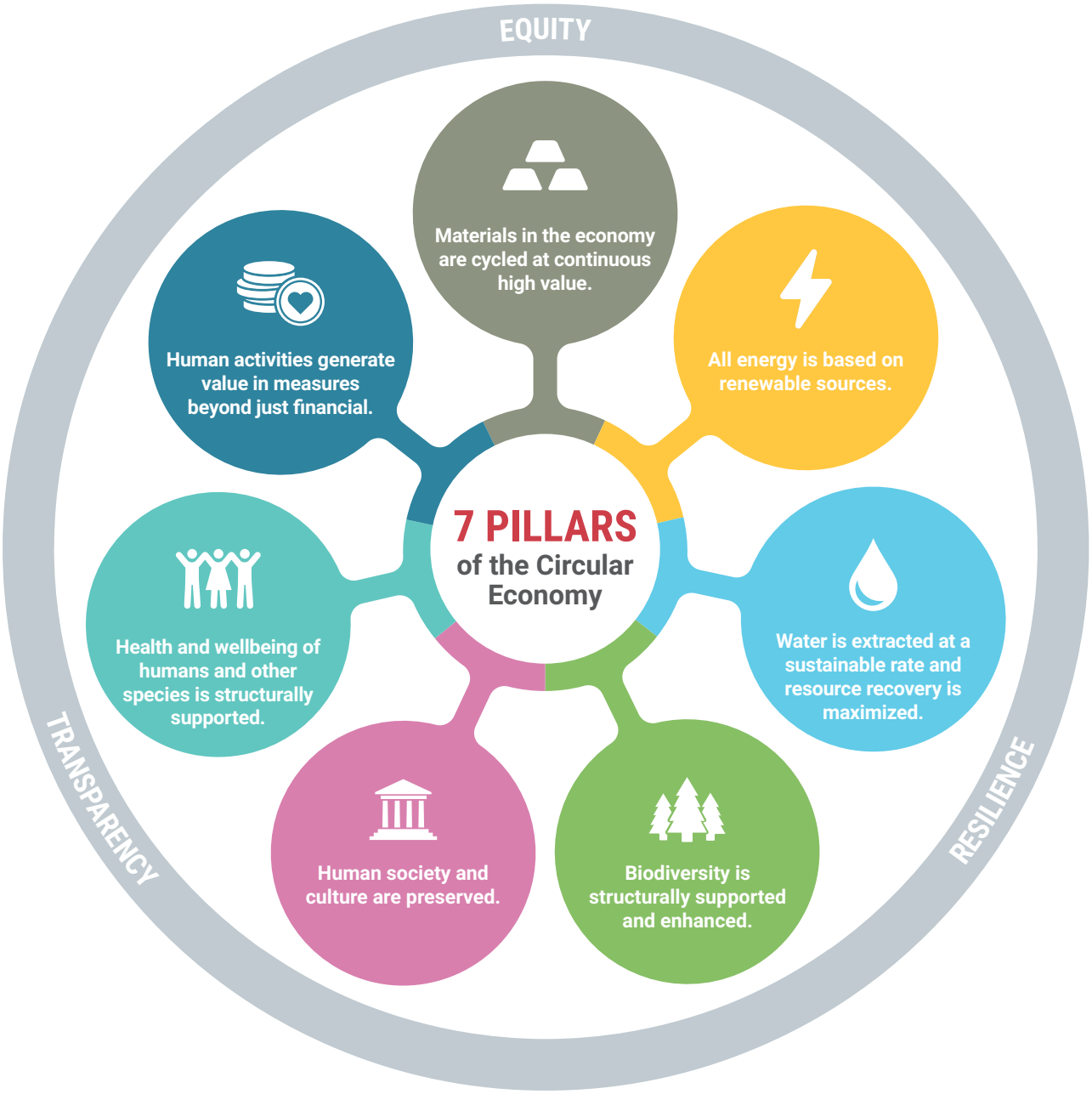
The alternative to a linear economy is a **circular economy,** one in which everything we depend on for our health and wellbeing is carefully preserved. This includes preserving the value of products, but also the natural capital of the environment on which we depend. It goes beyond simply recycling, to redesigning our economic system as one that is regenerative and resilient.

One of the key principles of the circular economy is the preservation of material complexity and value. Once labor, energy, and materials have been invested in creating products that are highly refined or complex, we must preserve the value of that investment for as long as possible by keeping products, components, and materials cycling in our economy at as high a value as possible. This requires:

- Designing products first of all for a long lifespan, but ultimately for repair, refurbishment, and recyclability.
- Cascading products and materials, which means using them at their highest value (e.g. food or feed) before cycling them into lower complexity products (e.g. nutrient elements).
- Building new business models and value chains that can capture value through cascading - a circular model requires cross-sectoral and supply chain cooperation.
- Creating physical (e.g. infrastructure), economic, political, and social structures which support circular models.
- Further supporting the environment by minimizing the disruption to natural systems from resource production and extraction, and eliminating toxicity along the supply chain.

The Linear Economy an unsustainable model

The Circular Economy beyond zero waste



One of the reasons the circular economy is becoming so widely adopted is that maintaining material complexity has enormous macro-economic potential for keeping value in our economy. Another reason is that it can create new jobs - circularity means, in many cases, substituting labor for additional material consumption (e.g. through repair and refurbishment). However, circularity cannot be only about value and jobs. There are many pathways to achieving circularity and not all of them are desirable. We could imagine a circular economy where all materials are recovered and cycled at a high value in conditions that negatively affect the environment and human health, for example. For this reason, we always use a holistic definition to measure progress towards the circular economy (our Seven Pillars of the Circular Economy), to ensure there is no problem shifting.

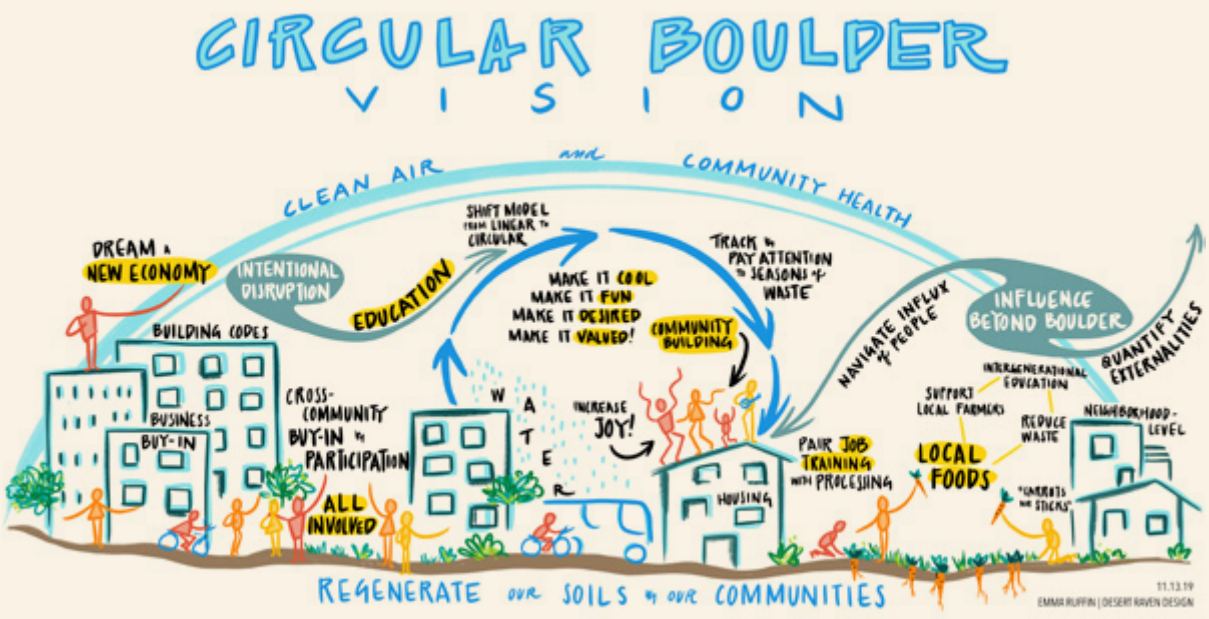
03

VISION FOR BOULDER

On November 13th, we hosted a public workshop to co-develop a vision for a Circular Boulder. We invited the community to think about how Boulder's unique characteristics could support circularity, and how circularity could support other values the community wants to foster locally. The following pages outline a first draft of this vision.

The vision is organized by three themes explored in the workshop:

1. Environment & Resilience
2. Society
3. Economy & Equity



Graphic recording interpretation of the workshop events and discussions, by artist Emma Ruffin (Desert Raven Design).

ENVIRONMENT & RESILIENCE

A circular Boulder means creating a resilient, regenerative environment for all species - including humans - acknowledging that all life is interdependent. In 2050, Boulder has shifted to a new paradigm in which the economy and society are understood as subcomponents of the natural environment. The community is built around a shared understanding that the health of natural systems underpins all of human wellbeing, and ecosystems are supported to provide a safe and habitable environment that can in turn support a thriving community.

One critical means of supporting the environment is reducing consumption by way of a more circular economy. Simpler living and personal efforts to reduce unnecessary consumption become the norm, but repair, refurbishment, and reuse ensure the same standard of living while reducing the need to buy new products. In the 20s, the local popularity of repair and reuse is scaled up to the point where most of the city participates in product lifespan extension programs. In the 30s, many companies switch to product-as-a-service models, renting products and taking them back for repair and reuse. By 2040, every major store in the city sells second-hand products in addition to new ones.

As Boulder reduces its impact footprint to within the city's boundaries, it continues to make more of the surrounding natural landscape available for wildlife. Outside the city, Boulder acts as a good steward to a wild natural environment that is allowed to thrive for its own intrinsic value. The city works to ensure that visitors and newcomers to the area are informed about stewardship practices. Inside the city, parks and greenways ensure that the urban environment also supports wildlife. Vegetated, living roofs and facades contribute to the health and happiness of the Boulder community.

Beyond increasing green space in the built environment, Boulder has begun to function more like an ecosystem, with its own local cycles of energy and materials. When buildings are torn down, or products reach the end of their lives, they are remade into new buildings or products. Water demand is reduced and wastewater is recovered and cascaded into local uses like irrigation before being returned to the creek for downstream users. Hot and cold energy is recovered from the built environment, stored, and used to offset energy use. Instead of being only a consumption center, Boulder begins to balance out its demand with local production.

Food and nutrient cycles are entirely locally closed, and by 2035 the volume of food and nutrients entering and leaving the city is balanced. Large volumes of food are produced and processed for local consumption: not only in community gardens ubiquitous in the city's residential areas, and in regenerative low-impact agricultural systems in the Open Space surrounding the city, but also through intensive landless food production in the urban and commercial areas of the city. The landless systems are kept low impact through industrial symbiosis: waste heat, emissions, wastewater, and organic wastes and nutrients are cycled into food production.

Stimulating local food sovereignty is just one way the city has created an environment of local resilience. Throughout the 20s and 30s, the city has adapted to increasing environmental pressures, mainly by adopting circular building practices and nature-based solutions. Native vegetation that can resist pests and thrive in local conditions has been used to support biodiversity, buffer rainwater, prevent heat stress in the summer, clean polluted air, and provide shade for the city's many cyclists, pedestrians, and locals using public transportation.

Local resilience is also measured by the level of knowledge and social capital within the community. One way the City ensures resilience is through intergenerational knowledge transfer. A circular Boulder fosters close social connections between various members of the community, including across generations. Key skills related to production (e.g. farming), processing, and maintaining or repairing materials or products locally is transferred to younger generations through mentorships, apprenticeships, and community activities and events.

SOCIETY

Creating a circular economy in Boulder requires a major shift in perception, starting with the local culture. Since the 2020s, the city has actively fostered a sense of personal responsibility and community around the circular economy, catalyzing local transformation. Arts and education campaigns have made circularity cool and desirable, with key role models playing a central role in shifting the cultural norm towards less material-intensive lifestyles. An upcycled art gallery and store that anyone can participate in has brought circularity to the community. In other public spaces, such as bus stops, on social media, and in supermarkets, messaging about circularity reaches a broader public - for example, there is messaging about thrifting and regifting around holiday times, and repair and purchasing for durability, as an alternative to consumerist habits.

Boulder's circular culture has transformed the community's conception of happiness from material possessions to experiences and social connection. Individuals and organizations in Boulder engage in and actively promote the thoughtful use of materials and products in a way that maximizes the joy and satisfaction of all community members. This evolution of the city's culture has created an environment where behaviors benefiting the community, the economy, and the environment are both convenient and desirable.

Part of the cultural shift has also included changing the perception of work relating to material and product manufacturing and maintenance. Trades like cobbling, carpentry, tailoring, and handywork have become more respected occupations in the community as digital technologies make it easier for locals to find options to repair or refurbish anything they own. Apprenticeships to learn these trades have become more common, especially for young people in the community. Eliminating local sales tax on second-hand items provides a further incentive for increasing reuse and sharing in the community.

In addition to the cultural shifts that have taken place, a social shift has enabled adoption of the circular economy, while also supporting the wellbeing of local communities. Community activities such as workshops, local markets, and reuse and recycling events bring social cohesion to the city, while also providing a direct means to reduce consumption. Individual connections through mentorships and matchmaking bring people together: seniors are connected with mentors who help them downsize, new parents are connected to hand-me-down networks, university freshmen are connected with the graduating class and taught thrifting skills. This social shift towards greater connections within and between communities is reflected in the way that Boulder includes all members in critical decision-making for the circular economy. In Boulder, all community members have a say in community decisions and have access to a high degree of self-determination in their personal and professional lives.

ECONOMY & EQUITY

In the year 2050, Boulder has a thriving, circular economy that generates and preserves value locally, including value beyond financial measures. The circular economy supports health, wellbeing & happiness of the local population. Financial value is only one means to this end and the city of Boulder has designed a system that in many cases generates value for the community, independent of finance and materials. A strong sharing economy, local direct exchanges of goods and services, a stronger repair culture, second-hand markets, and circular business models such as product-as-a-service all help bring the city's consumption-related impacts within the boundaries of the city itself.

As a circular economy requires a re-imagination of the entire economic system, the redesign process actively ensures that the voices of under-represented populations are heard, in order to enable a new system which creates equal opportunities to share in the value of the new economy. Starting in 2019, the city has been actively engaging the community on the topic of the circular economy to ensure everyone has a voice in designing the new economy. Training and education programs, entrepreneurship support, and jobs serve the needs of all local communities and provide pathways towards exciting and meaningful participation in the circular economy.

During the transformation from a traditional linear economy to a circular one, Boulder has made use of its strengths in cleantech and IT, biotech, natural foods, and the outdoor industry. Between 2019 and 2030, Boulder tested and scaled up new circular business models in these sectors first, going beyond recycling towards a broader concept of value preservation. These efforts are supported by holistic and comprehensive economic strategies at an organizational, city, and regional level. This includes addressing barriers such as imbalanced tipping fees at landfills, while growing regional end markets and demand for circular products and materials through procurement and other incentive frameworks. These strategies also provide opportunities for experimentation, innovation, and piloting locally. The city's new Innovation Hub, opened in the mid 2020s has become a key starting point by providing space and equipment to local entrepreneurs.

A circular economy means more jobs than an extractive economy, as circularity means substituting labor and technology for additional raw material consumption. To provide space for a growing local workforce, the city provides a pathway for circular urban development, including elements like adaptive design, multi-use buildings (e.g. office during the day and restaurant at night) and shared spaces (micro apartments with large communal shared spaces). Reuse of building components and materials cuts the costs and impacts of new development, and a model of the "urban mine" connects developers to secondary materials.

By 2030, Boulder's successful pilot projects and position as a frontrunner in the circular economy has led other companies and institutions in the region to follow suit. While circular economy initiatives begin as distinct efforts undertaken by separate organizations in the 2020s, by 2030 the local economy stimulates a broader culture of cooperation, with clusters of companies participating in cross-sectoral collaboration. Knowledge sharing and networking helps companies learn from each other, identify opportunities for industrial symbiosis, and work together across the value chain to preserve and recover value from products and materials.

In 2035, the successes of Boulder are becoming nationally and globally recognized, and applied in other cities, having a systemic ripple effect outside the scope of the city. More importantly, because of the adoption of circular practices in neighboring cities, the city of Boulder is able to collaborate more broadly with other Front-Range communities and close significantly more material cycles in the region. By 2040, the consumption needs of the community are largely met by end markets and manufacturing within the region itself. In achieving this, the region reaches a degree of self-sufficiency surpassing even the frontier era, leaving the local economy more resilient to global shocks and market shifts. Companies born from the Innovation Hub and other circular initiatives begin to have a broader impact nationwide.

04

CIRCULARITY OF BOULDER

Over the past several months, the City of Boulder and Metabolic have been working to develop a complete picture of how circular Boulder is, where the current resource system is resulting in key problems or hotspots, and where there might be opportunities for closing material, energy, or water cycles locally.

At the core of this work lies what is called an **urban metabolism** analysis. Just as animals take in materials (food), water, and energy, transform them through metabolic processes, and produce wastes (and life!), cities also have a metabolism. Mapping that metabolism quantitatively through a **material flow analysis** (MFA) - as well as working to understand the physical, social, economic, and political processes underlying it - helps build a deep understanding of the state of circularity.

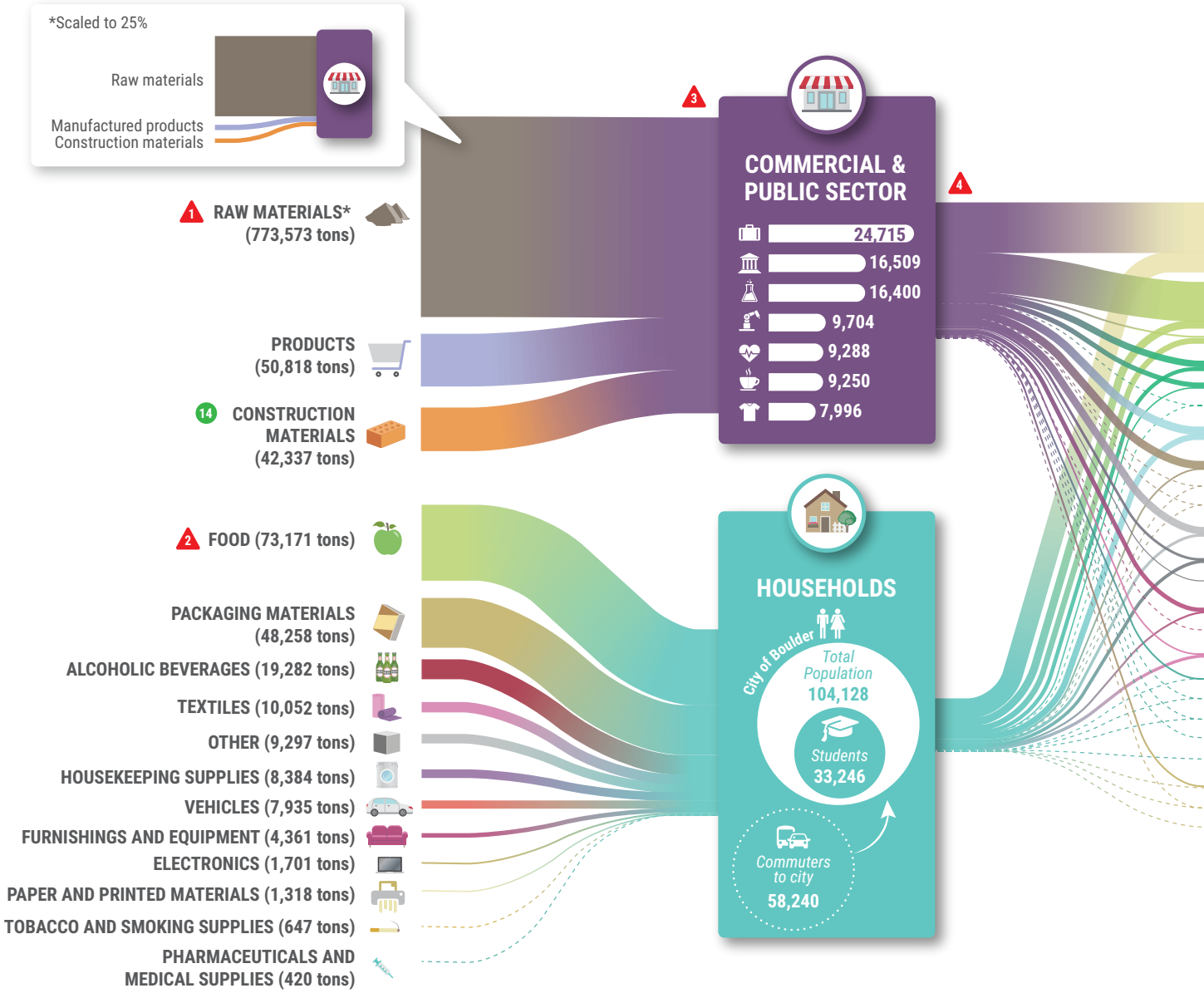
The material flow analysis is complemented by this contextual understanding, built up through dozens of interviews, site visits, research, and analysis of impacts and value. Through this process we have worked to understand two things:

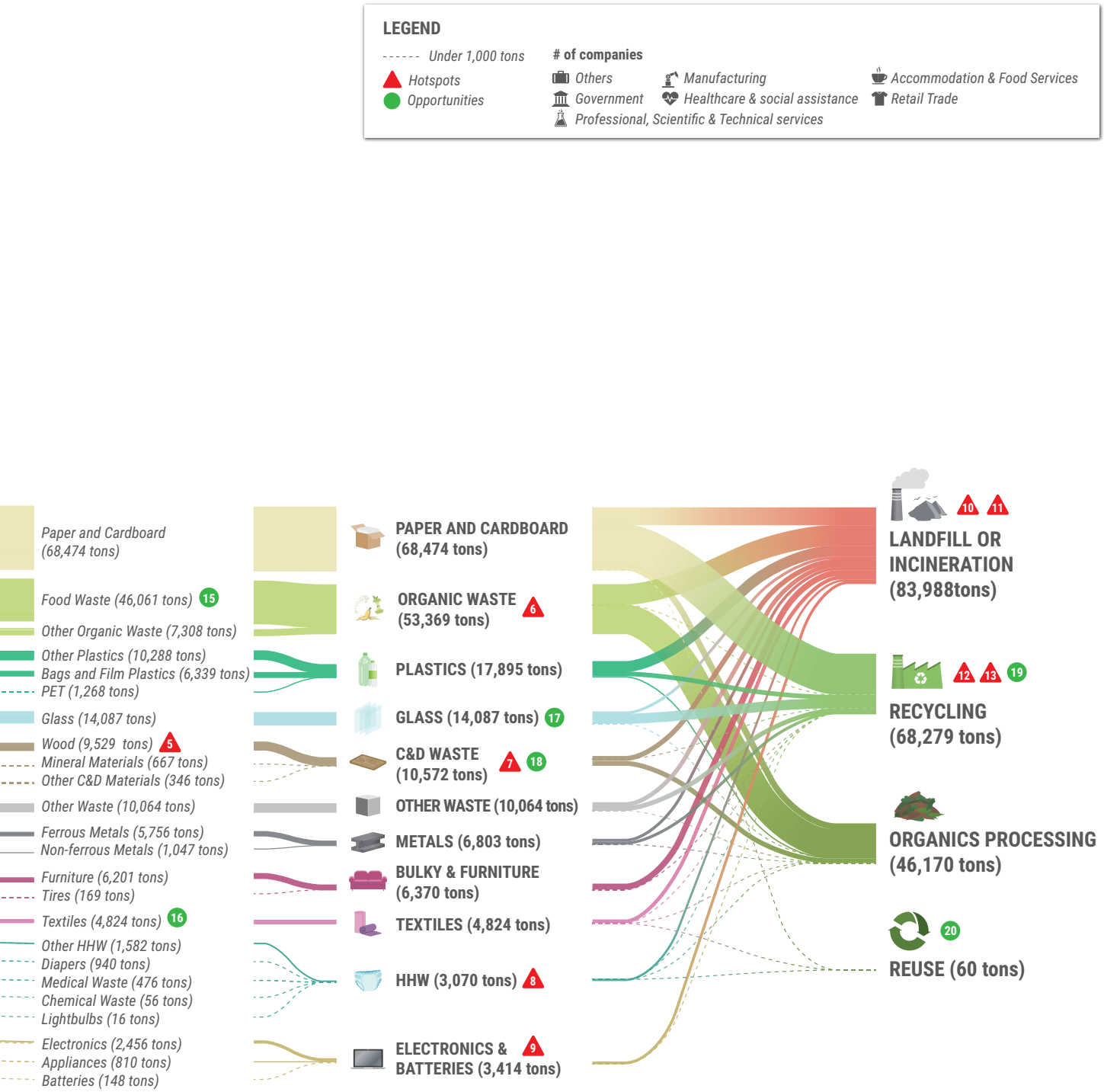
- What is not going well in Boulder that we can address? What are the main impacts created by the current resource system? What are the structural barriers that are preventing a shift towards circularity in the city?
- What is going well in Boulder that we can build upon? What foundations for circularity are already in place? What are the strengths of the city that can support a transition to a circular economy?

These **Hotspots** and **Opportunities** are highlighted in the material flow analysis graphics on the following pages. A few of these we found so essential that we explored them further, highlighting the scope and importance of these issues as first areas to focus efforts.

City of Boulder Material Flow Analysis

This is a Sankey graphic, where the thickness of each line represents the size of material flows (in mass) through the city of Boulder. The left-hand side of the graphic shows estimated material and product consumption of the city's households and organizations, based on average national consumption data, input-output data for sectors, and local tax data. The right-hand side shows all of the city's waste streams and how they are treated. Without data available from local companies, the information is still incomplete, and it is impossible to make a reasonable estimate on manufacturing material inputs or product output, so these are excluded from the picture.




LEGEND
Under 1,000 tons
Hotspots
Opportunities
# of companies
Others
Manufacturing
Accommodation & Food Services
Government
Healthcare & social assistance
Retail Trade
Professional, Scientific & Technical services
Paper and Cardboard (68,474 tons)
Food Waste (46,061 tons) 15
Other Organic Waste (7,308 tons)
Other Plastics (10,288 tons)
Bags and Film Plastics (6,339 tons)
PET (1,268 tons)
Glass (14,087 tons)
Wood (9,529 tons) 5
Mineral Materials (667 tons)
Other C&D Materials (346 tons)
Other Waste (10,064 tons)
Ferrous Metals (5,756 tons)
Non-ferrous Metals (1,047 tons)
Furniture (6,201 tons)
Tires (169 tons)
Textiles (4,824 tons) 16
Other HHW (1,582 tons)
Diapers (940 tons)
Medical Waste (476 tons)
Chemical Waste (56 tons)
Lightbulbs (16 tons)
Electronics (2,456 tons)
Appliances (810 tons)
Batteries (148 tons)
PAPER AND CARDBOARD (68,474 tons)
ORGANIC WASTE (53,369 tons) 6
PLASTICS (17,895 tons)
GLASS (14,087 tons) 17
C&D WASTE (10,572 tons) 7 18
OTHER WASTE (10,064 tons)
METALS (6,803 tons)
BULKY & FURNITURE (6,370 tons)
TEXTILES (4,824 tons)
HHW (3,070 tons) 8
ELECTRONICS & BATTERIES (3,414 tons) 9
10 11
LANDFILL OR INCINERATION (83,988tons)
12 13 19
RECYCLING (68,279 tons)
ORGANICS PROCESSING (46,170 tons)
20
REUSE (60 tons)

▲ *Hotspots* ● *Opportunities*

▲1 Due to fossil fuel production in the state, virgin plastics are very cheap, resulting in little incentive for recycled plastics.

▲2 There is a fairly low amount of local food production considering the motivation to buy local products. High prices for crops produced in the area lead food processors and breweries to import raw materials.

▲3 There is currently a lack of data on material consumption by the city's residents and organizations. Making an estimation of material throughput is complicated by in-commuters, students, and tourists.

▲4 Various retail and restaurant locations have their own signage and infrastructure for recycling, which can be confusing to some people and result in contamination, especially as many commuters from outside the city are used to a different system.

▲5 Waste wood is becoming available due to emerald ash borer infestation, which potentially threatens up to 25% of the urban canopy. This wood is however put into a variety of productive uses, including mulch, biochar, and lumber.

▲6 The high cost of compostable bags (ten times more expensive) is a barrier to encouraging composting participation.

▲7 50% of C&D wastes are going to landfill as there is no local recycling facility. Fort Collins is currently developing a construction and demolition recycling facility, while Boulder County is also considering such a facility, opening up new local opportunities.

▲8 There are no easily-accessible locations for HHW recycling. The current location, while extensive and well-managed, is on edge of the city and difficult for some to get to.

▲9 There are no legal or financial consequences if locals throw away electronics or hazardous waste in the trash.

▲10 Recyclers in the Boulder area face difficulties in using railways for waste transport as priority is frequently given to fracking & natural gas products. Truck freight is more expensive in the region, again due to the prevalence of service businesses.

▲11 Boulder, like the rest of Colorado, has extremely low landfill tipping rates which create an incentive to send materials to landfill instead of recycling. Recycling tipping fees are more than twice as high as landfill fees.

▲12 When materials are "downcycled", they are put to a different use in a form where they are likely never used as the original material again. Most concrete and textiles are downcycled into filler material, rather than being used as concrete or textiles.

▲13 Weak local end markets for recovered material are a barrier to recycling, partially due to the prevalence of service businesses instead of manufacturing. The state is working to grow local end markets through a business incubator and other resources.

●14 Climate change adaptation will mean new buildings and renovation, creating new demand for and a growing waste stream of construction materials in the coming years.

●15 While many organics still go to landfill, there seems to be a strong foundation of community-led composting and food rescue initiatives in Boulder. For example, the Boulder Food Rescue diverted around 150 tons of edible food from the landfill in 2014.

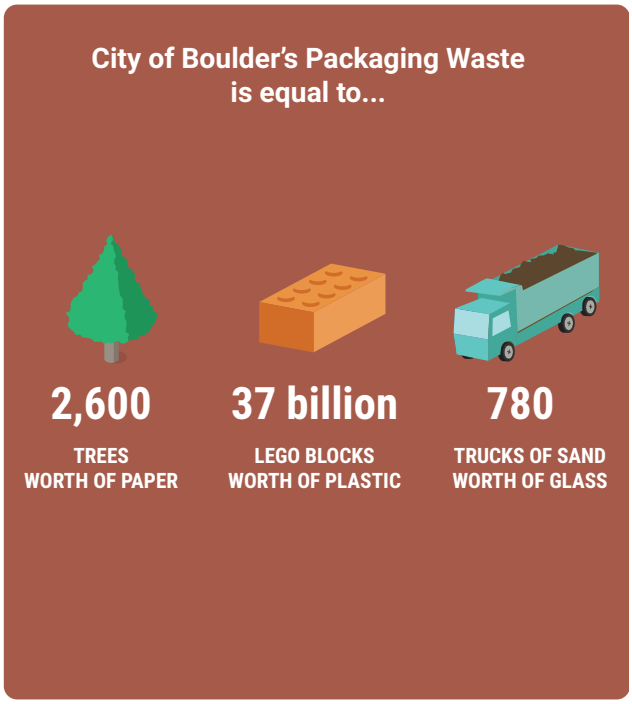
●16 The community shows a lot of enthusiasm for repair workshops. Repair clinics at BLDG 61 hit 60 attendees (UFixit) and 30 attendees (Sewing Rebellion) every time. These programs could be expanded so reparable items are not thrown away.

●17 One area of success in recycling is glass, due to local end markets for glass bottlers. 77% of glass waste in Boulder is recycled.

●18 Commercial building projects, which account for the greatest volume of C&D waste are exempt from construction and demolition recycling requirements, while non-commercial building and renovation projects are insufficiently monitored for compliance.

●19 While many cities in the United States struggle with the Chinese ban on contaminated recyclables, Eco-Cycle, which has newer sorting equipment for plastics and good relationships with national buyers, actually increased throughput.

●20 Even though there is little data available on a city level, many local organizations have comprehensive reuse programs. Also considering secondhand markets, the community may be diverting much more waste from landfill than the data shows.



Around $2.3 million worth of valuable materials are being sent to the landfill in Boulder - mainly packaging materials, which make up 28% of the city's waste.

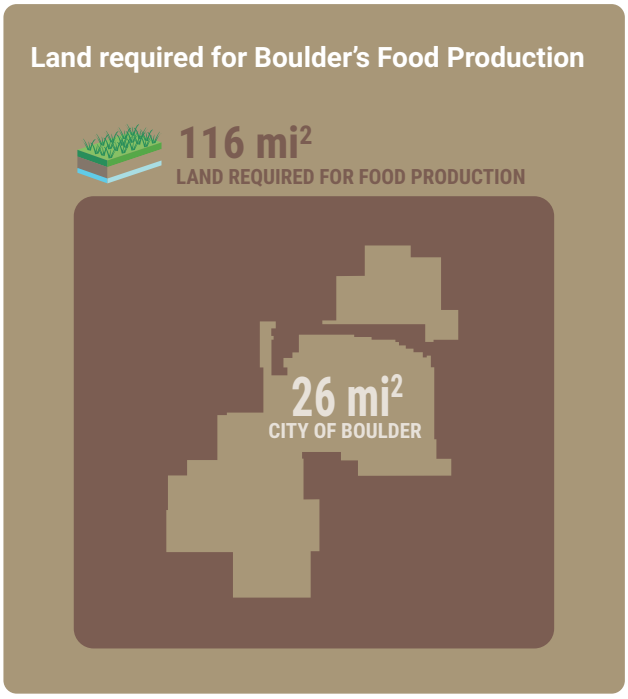
Compared to other U.S. cities, Boulder consumes more paper and glass per capita and less metals and plastics, which shows a preference for these packaging materials (potentially because these materials are generally perceived as more sustainable).

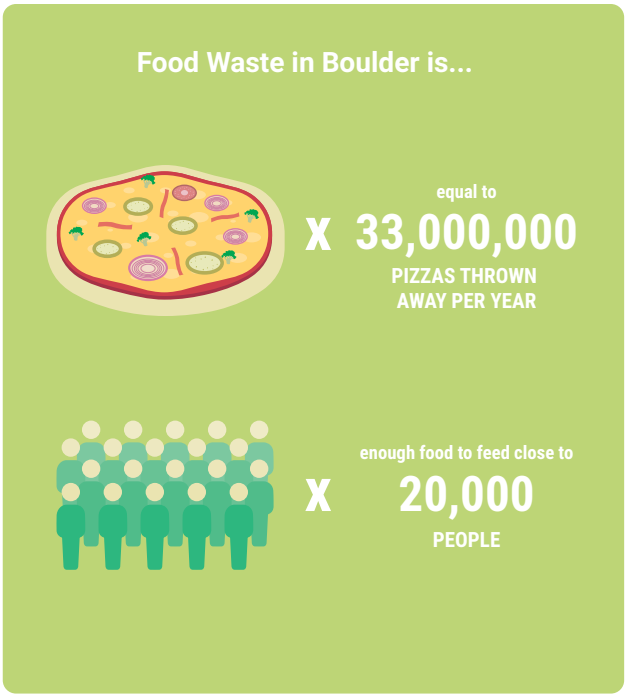
Paper and plastics recycling is a gap in the region. While developing local end markets is one way to create a more circular city, another option is to move towards more reusable packaging models and eliminate the material consumption entirely. Strategies to do both simultaneously will be key to achieving zero waste by 2025.

Another big portion of the city's waste is from construction and demolition. Globally, construction materials account for nearly a third of all material consumption and around 10% of all waste.

Since Boulder is growing, more materials are going into the built environment than are coming out. Even so, it is important that all construction materials are cycled back into use to meet the size of the demand. Additionally, unlike most products, elements from buildings, such as doors, windows, fixtures, etc, are also particularly good candidates for direct reuse. *Resource Central* in Boulder is already a great example of building component reuse.

Scaling up reuse and establishing a facility for recycling mineral products from construction and demolition wastes (such as drywall, concrete, and bricks) will have significant immediate effects. On the longer term, adopting innovative circular building practices can ensure that buildings can be used for longer and that components and materials can be more easily recovered at the end of a building's lifespan.





As mentioned before, a city's impact extends far beyond its own borders, and nowhere is that more apparent than when you look at the physical footprint a city has for its own consumption. In particular, food production requires a large amount of land.

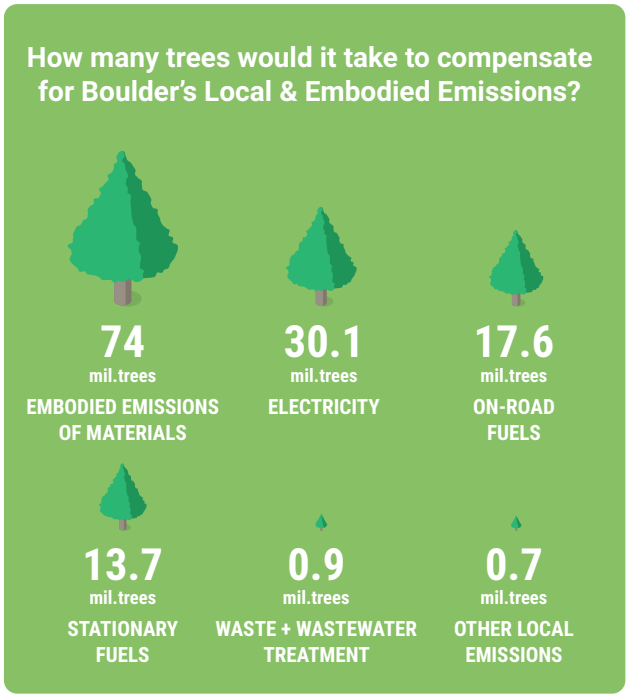
The land footprint for Boulder's local food production is around four times the area of the city.

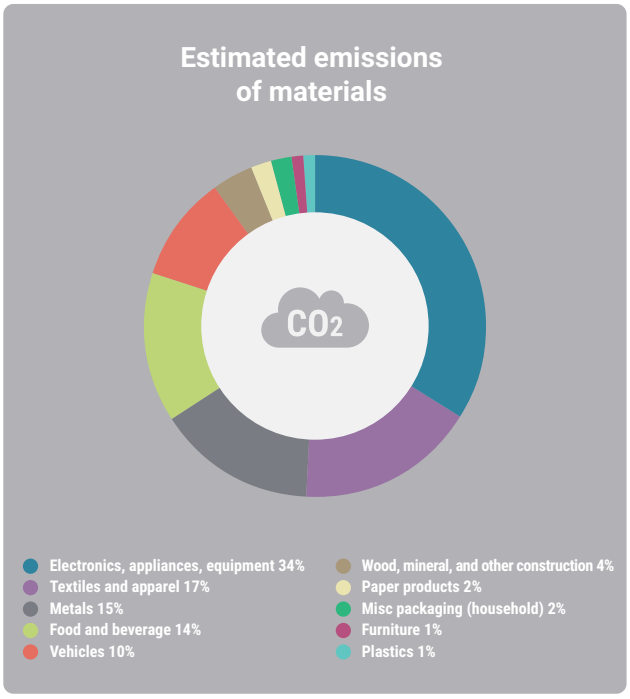
It takes a lot of creativity to imagine a city that can fulfill all of its own food demands locally, but moving in that direction is important for long term resilience and for closing nutrient cycles. Boulder is uniquely positioned in that it has a large amount of agricultural space which can be used for food production. On the other hand, to meet food demands without encroaching on biodiversity through agricultural expansion, a supplementary option is to build capacity for food production in urban and commercial areas.

In particular, landless indoor production systems offer a lot of promise: for one there is a lot of expertise in the area from local marijuana producers, and secondly it opens up opportunities for industrial symbiosis (using waste heat, waste, CO_2, nutrients, etc from local sources).

Precisely because of the impacts associated with food production, eliminating food waste should be another major priority - globally, nearly a third of all food is wasted before it ever makes it to the plates of consumers. Boulder is home to effective food waste diversion programs, such as Boulder Food Rescue, which should be scaled up and structurally supported through policy.

The value of compost is around 1/60th of the value of food (van der Zande, Dekkers & van Exter, 2018). Once food (or other organic materials) becomes waste, there are other higher value options before composting. Some food waste can be used as animal feed, to grow insects, for the extraction of valuable components (like specialty chemicals), or to make biomaterials like textiles or plastics. Exploring options such as these can mean that the value of the materials is maintained for longer.





Most greenhouse gas emissions result from the production and transportation of products, which largely happens outside of cities and even outside of the United States. For this reason, the United States is a net importer of "embodied" CO_2 emissions (OECD, 2019).

In a city such as Boulder with a strong service economy, embodied emissions become even more important. Efforts to reduce local sources of emissions, for example from local energy consumption, are on the right track. However, to truly address Boulder's contribution to climate change, it is necessary to develop a vision for reducing impacts outside of the city boundaries.

In order to understand the potential for emissions from local demand, we applied emission factors (from lifecycle assessment data) to the estimated local material and product consumption. Our assessment is far from being a complete inventory of consumption-based emissions (as we are missing some consumption data and emissions factors), but provides a starting point for understanding the order of magnitude of embodied emissions.

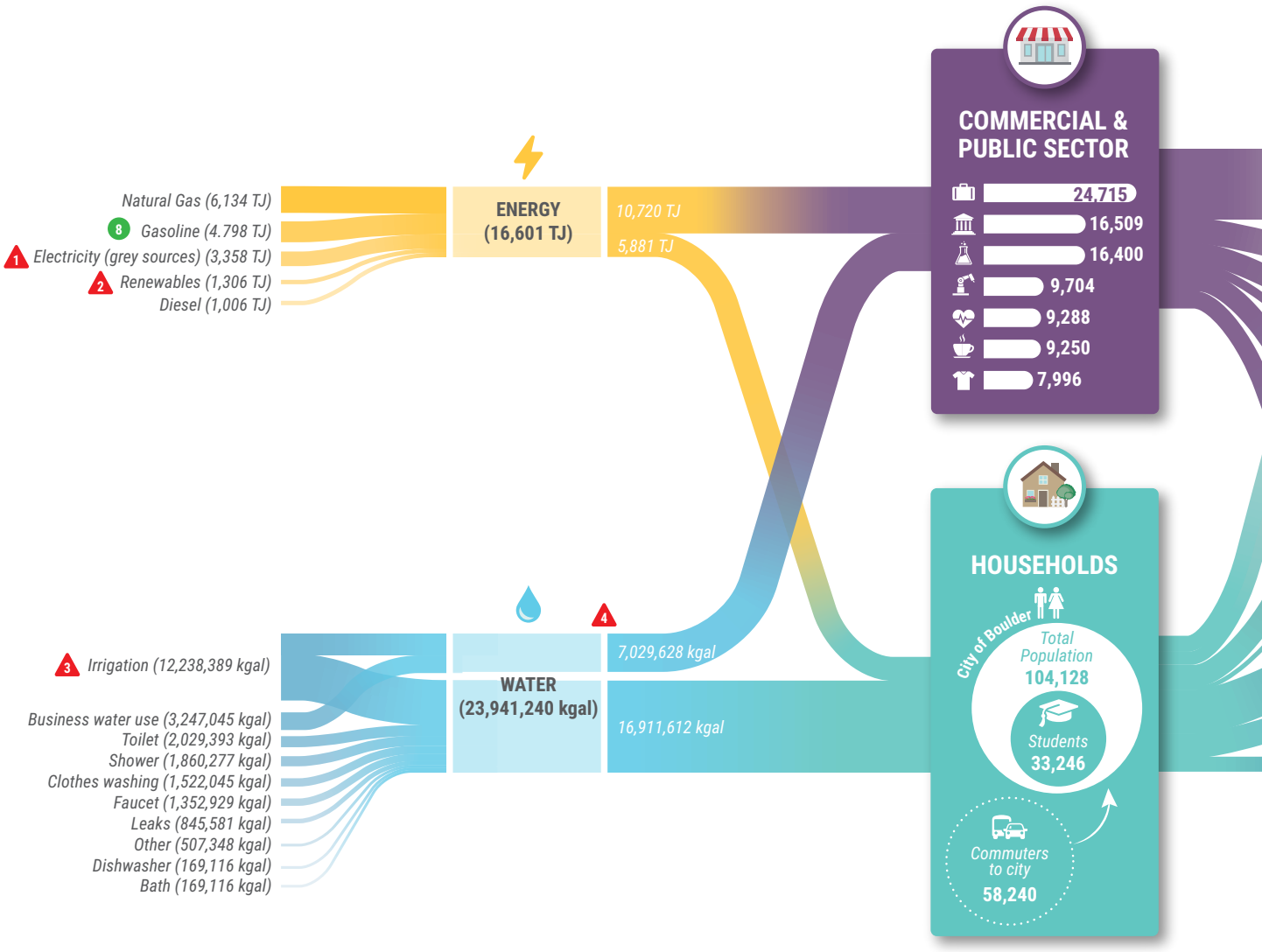
What we found is that the size of embodied emissions (nearly 1.8 million metric tons) is **larger than** all local sources of emissions put together (around 1.7 million metric tons). That means that even a small change in circularity can have an enormous effect on overall impact. If actions such as repair or reuse can reduce consumption by even a few percentage points, this can reduce emissions more than making significant reductions in local electricity consumption or fuel use.

Carbon is one of the most basic building blocks that we need to consider in the circular economy. The city is currently piloting carbon sequestration programs, including "carbon farming", which increases the carbon stored in soils. These types of programs should be expanded along with a broader vision on the longer term on how to create a fully circular carbon cycle, especially as we make a shift away from fossil fuels and need to find new sources of carbon.

> **"The size of embodied emissions is larger than all local sources of emissions put together. That means that even a small change in circularity can have an enormous effect on overall impact."**

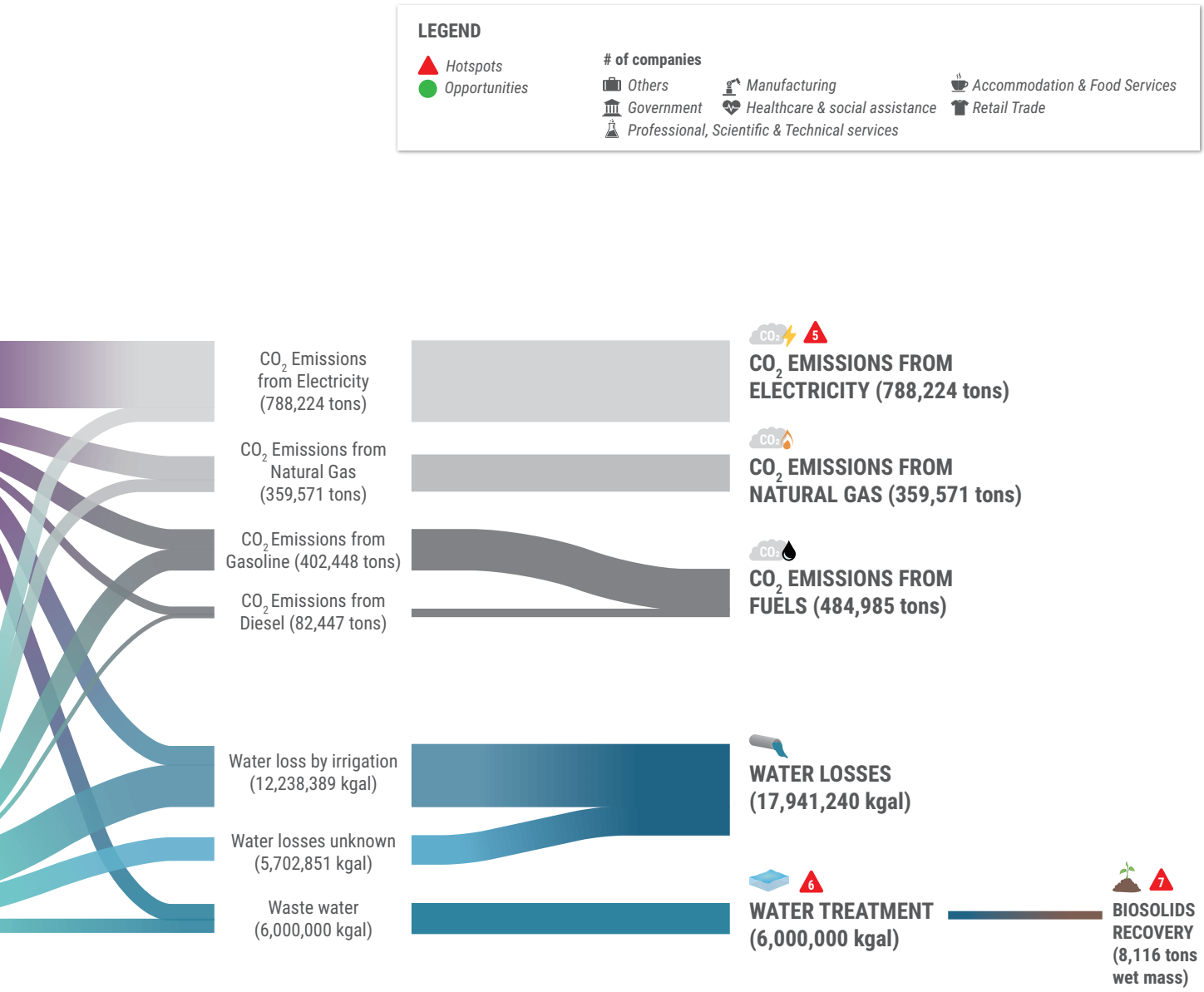
City of Boulder Water, Energy, and Emissions Flow Analysis

This is a Sankey graphic, where the thickness of the lines represents the volume of water, energy, and emissions in the city of Boulder. The left-hand side shows water and energy consumption of the city's households and organizations, while the right-hand side shows all of the wastewater and CO_2 emissions.



▲ *Hotspots* ● *Opportunities*

1. Despite strong regulations and ambitions for energy performance, Boulder lags behind for Energy Star ratings compared to other cities (e.g. Fort Collins and Denver). Risk aversion may hamper the application of more innovative green building practices also relevant for the circular economy.
2. The city has large organizations who require consistent and high amounts of energy (e.g. data centers, research labs, marijuana growers). A transition to renewable energy is considered a potential risk if the stability of supply cannot be guaranteed.
3. Despite regional water scarcity, around half of water is used for irrigation of green spaces, with a prevalence of non-native landscaping species ill-suited to the climate.



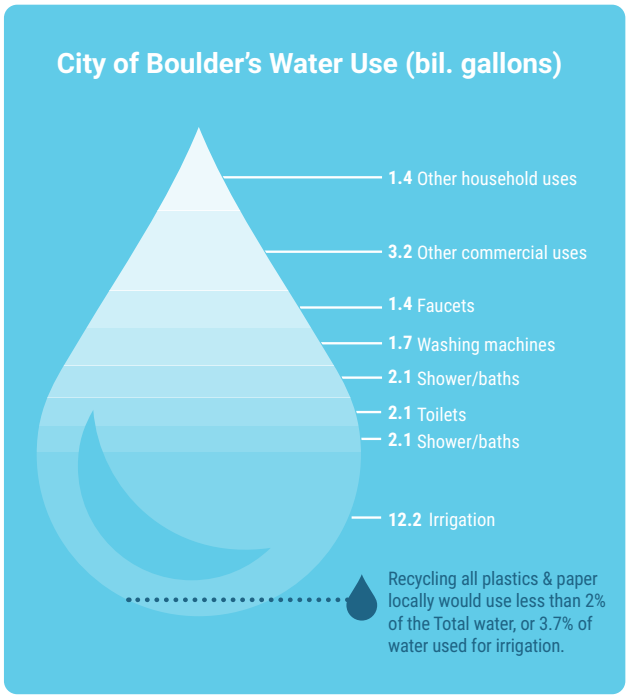
4 Water rights produce perverse incentives - if less water is consumed, then water rights are lost; this fosters a disincentive for water-saving measures and reducing irrigation.

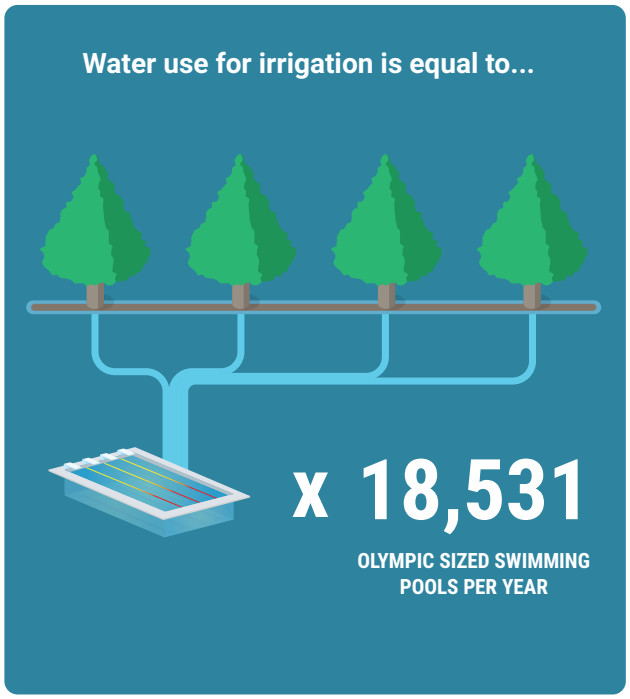
5 Emissions from electricity are higher than natural gas even though the consumption of electricity is lower than natural gas (in TJ energy). This is due to the large share (~39%) of coal in the current energy mix.

6 When there is heavy rainfall, treated wastewater is simply dumped into the creek, while this water could have local applications (such as for irrigation water).

7 Biosolids recovery and land application from wastewater treatment has been successful. However, this only returns a small share of nutrients to the agricultural cycle (around 28% of phosphorus & 17% of nitrogen).

8 The number of people who walk and bike in the city is more than 4x the national average, and far less people use cars to commute (50% vs. 72%). However, a lack of shelter from the elements is one barrier identified to increase alternative modes of transport.





While Colorado's "300 days of sunshine" might be a good thing for tourism and alternative modes of transportation, it does mean that water scarcity is something the region has to contend with. This also has implications for the circular economy - producing and recycling materials requires water. Additionally, minimizing material consumption through nature-based solutions like vegetation for cooling, pollutant removal, or stormwater buffering will mean increasing water demands.

> **"Currently in the state of Colorado, around 50% of all household water consumption is used for irrigation."**

One of the reasons this water use is so high is that a large share of the city's vegetation is not suitable for the local climate. Shifting to native species can reduce these demands. However, it would also be possible to conserve some of the drinking water used for irrigation by using gray water (for example treated wastewater) to offset some of the irrigation demands.

Linked to the city's wastewater is the issue of nutrient cycling. The city has a biosolids program, which returns some of the nutrients from wastewater to land. However, there are more nutrients and potentially other valuable components within that wastewater which could be recovered and returned to material cycles.

Goal: minimize waste production per capita

4.4 lbs/person/day U.S.

10 lbs/person/day CITY OF BOULDER

One of the key goals the city has outlined in its zero-waste plan is to minimize overall waste production per capita.

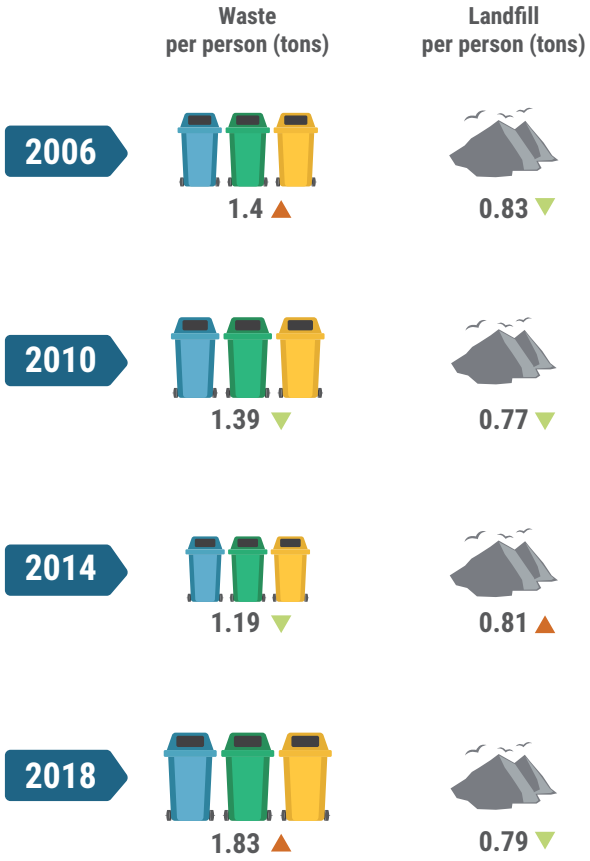
However, there is one crucial complicating factor: incommuters. A lot of waste generated is counted in the city's waste production, while in-commuters are not counted in the population.

While all cities have a large number of in-commuters coming from more affordable neighborhoods outside of city limits, exceptionally high housing prices in Boulder make it an extreme case.

> **"An estimated 58,000 people travel into the city of Boulder every day for work, as commuters make up 60% of the local work force."**
>
> -(City of Boulder, 2019 Community Profile).

While this has implications for emissions from car traffic, it also means that a lot of waste generated is counted in the city's waste production, while in-commuters are not counted in the population. In order to monitor this metric, and be comparable to other cities, an adjusted or weighted metric will need to be created that takes into account the effect of commuters.

***Waste Generation Per Capita** over the past years shows no clear trends, likely complicated by the changes in in-commuters*



Goal: 85% waste diversion from landfill by 2025

59%
SINGLE-FAMILY HOUSEHOLDS

44%
MULTI-FAMILY HOUSEHOLDS

58%
COMMERCIAL

waste diversion from landfill in 2018

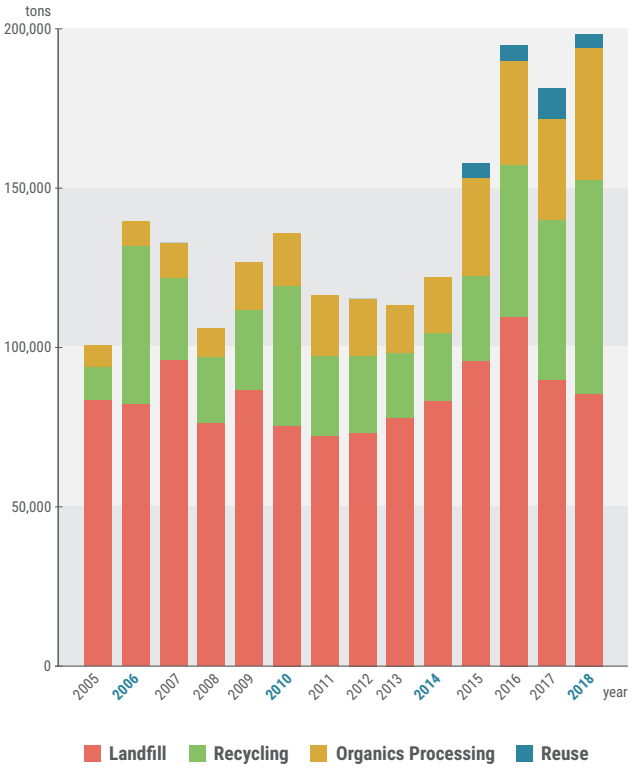
As described in the vision, going beyond only looking at waste generation, a shift towards a circular economy can bring other benefits such as increasing employment, stimulating innovation, and creating more equity. On the other hand, it could also be implemented in a way that has negative impacts. For these reasons, the city should work on developing a comprehensive set of Key Performance Indicators (KPIs) which can set the baseline, help to evaluate trade-offs, and support the measurement of progress towards the circular economy.

Overall, Boulder's current waste diversion rate of 57% is impressive. It places the city in the top tier of cities around the world for composting and recycling rates. Even so, reaching an 85% diversion rate in just five years is an extremely difficult target to meet and will require significant action.

Furthermore, the most obvious, simpler ways to increase diversion rates have already been implemented; the next five years will mean addressing the root causes behind waste production.

In the coming chapter, an initial roadmap is outlined. It points to ways in which some of these more structural challenges can be addressed, such as policy developments, developing networks, creating an environment for knowledge transfer, and building economic incentives that stimulate, rather than hamper, entrepreneurship and innovation.

***Waste Production and Treatment** - while the waste diversion rate to reuse, recycling, and composting is steadily increasing, so is the total per capita waste production*



05

ROADMAP

To meet Boulder's ambitious zero-waste goals, urgent action is required in the coming years. While the City will continue to develop a comprehensive action plan in 2020, the roadmap on the following pages lays the basis for the types of actions that are required in the near term. Milestones are shown, along with the enabling actions, or interventions, that make it possible to achieve the milestones. Each of the interventions is depicted with the milestones they support, highlighting some of the more foundational actions that need to be taken. Key themes in the roadmap include:

Developing critical knowledge: for example mapping out key waste fractions and opportunities for industrial symbiosis, building an urban mining tool, and developing guidelines for circular construction or procurement.

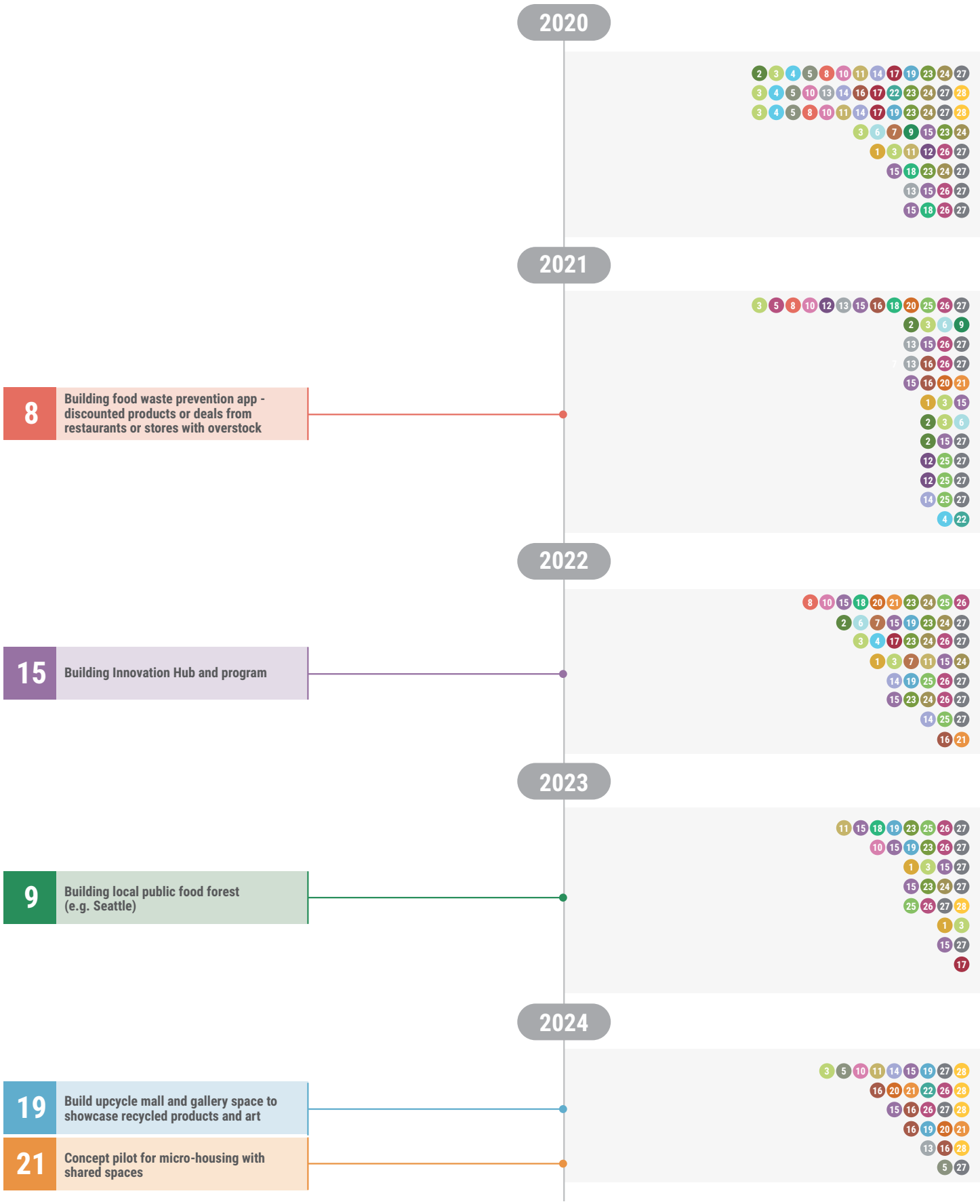
Building a strong circular network: establishing networking events, connecting people with extra space or specific skills with those in need, and enabling the sharing of best practices.

Engaging the public: bringing the voices of the community into the circular economy visioning and implementation plan and ensuring the public is aware of what is happening by monitoring and reporting on the state of circularity in the city.

Working closely with other city departments: spatial planning for nature-based solutions, water treatment, requirements around construction and building codes, and many more elements of a circular strategy require a holistic vision and cross-departmental collaboration.

Changing policy, lobbying for change, and finding workarounds: the city can work to change local policy which could stimulate more circular economic activity - for example by reworking the local tax code, or banning food waste or single-use products. However, many of the perverse incentives embedded in current policy are outside the jurisdiction of the city. This includes regulations that hamper the use of organic waste from marijuana production and bulk food sales, or statewide regulation on landfill tipping fees. While the City cannot directly change these rules, they can lobby for change and find ways to overcome these barriers locally.

Establishing a strong economic basis for circular entrepreneurship and innovation: the City is already developing plans for an Innovation Hub to accelerate scale-ups belonging to local circular entrepreneurs. Beyond this, the City can also work to alleviate barriers within the startup ecosystem, develop revolving funds or a local investment platform for companies, or build a certification standard for local circular products. Importantly, one of the key ways the City can support circular companies and initiatives is by acting as a launching customer, adjusting its own internal procurement to favor circular products and companies, or taking the lead in developing pilots that pave the way for others to follow.


2020
2021
2022
2023
2024
8
Building food waste prevention app - discounted products or deals from restaurants or stores with overstock
15
Building Innovation Hub and program
9
Building local public food forest (e.g. Seattle)
19
Build upcycle mall and gallery space to showcase recycled products and art
21
Concept pilot for micro-housing with shared spaces

Plan to ensure that everyone in the community is heard in the development of the circularity strategy
Develop framework of improved Key Performance Indicators and begin monitoring and reporting on circularity
Public communications strategy to bring circularity knowledge to the broader community
Take first steps towards a regional food vision - start developing a food action plan
Circular/local procurement policy at city level (city as launching customer, own buildings are circular buildings)
Program to reduce time and cost of establishing new circular businesses
Mapping local business wastes and raw material demands in detail to identify industrial symbiosis opportunities
Pass pending end market development center bill

Build a circularity partnership network within the city (e.g. with industry groups)
Adjusting spatial planning to allocate space to food production
Networking events for businesses to share best practices, form cross sectoral partnerships, and discuss opportunities for industrial symbiosis
Develop a model of the urban mine (materials in built environment that will become available over time)
Innovation challenge for green building design for modularity, adaptivity, and multiple uses of space (partner with CU environmental design)
Help create school curriculum that includes circularity (production, repair, sustainability)
Build community platform for managing urban gardens through an app
Community knowledge trading platform to facilitate intergenerational knowledge transfer on production and repair
Pilot marijuana dispensary reusable containers
Pilot reusable containers at local restaurants
Building an app to connect locals with people to repair anything from bikes, to clothing, to furniture and electronics
City sets up program for public space design to support a resilient, healthy, and productive natural environment

Establishing a local investment platform for circularity innovations (e.g. apps or technologies)
Setting up a revolving fund for community initiatives such as energy co-ops or lending libraries
Build a regional circularity network and strategy through partnerships in the front range
Re-evaluate food safety regulation barriers that inhibit circular business models
Dropping local taxes on secondhand goods to incentivize reuse
Developing data collection and overview of local spatio-temporal organic wastes at a high level of detail
Set up a fixed u-fix-it location with full-time staff for repair support
Semi-communal housing is part of the city's robust affordable housing program

Setting up an innovation contest on key local problems and problem materials
Allocating city-owned space to warehousing and (re)manufacturing space for circular initiatives
Advocate for school funding to circular education programs
Provide research funding and feedstocks for the development of bioplastic composting/organic waste bags
Expanding collection points for hard-to-recycle and hazardous materials throughout the city
Pilot large-scale school food garden
Re-evaluate regulations around the classification & use of hazardous wastes (e.g. health care & marijuana sectors)
Adjust spatial planning for walkability and public transportation

Gamification of circular behavior through local competitions or app with incentives
Continue to evolve building codes to stimulate circular innovation and green space in the built environment
Providing guidelines and training for local companies on circular renovation, construction, and deconstruction
Build platform to connect potential (part-time) tenants with available shared/temporarily unused space through an app
Evaluate options for district heating and cooling (heat-as-a-service)
Ban edible food waste from disposal

2025

- **6** Establishing community and school aquaponics/hydroponics programs
- **7** Pilot insect protein production (from food waste or other organic waste)
- **22** Boulder builds a resilient, healthy, and productive natural environment

2026

- **13** Building a comprehensive network of industrial symbiosis exchanges in Boulder
- **20** City builds a pilot building for multi-use sharing of space

2027

- **1** Establish productive food gardens at all schools
- **2** Community gardens and composting available in every neighborhood
- **18** Establishing an eco business park based on industrial symbiosis to attract sustainable manufacturing

2028

- **5** Eliminate all avoidable food waste
- **10** Building a comprehensive and centralized reuse market for the city
- **17** Minimizing individual car use in the city

2029

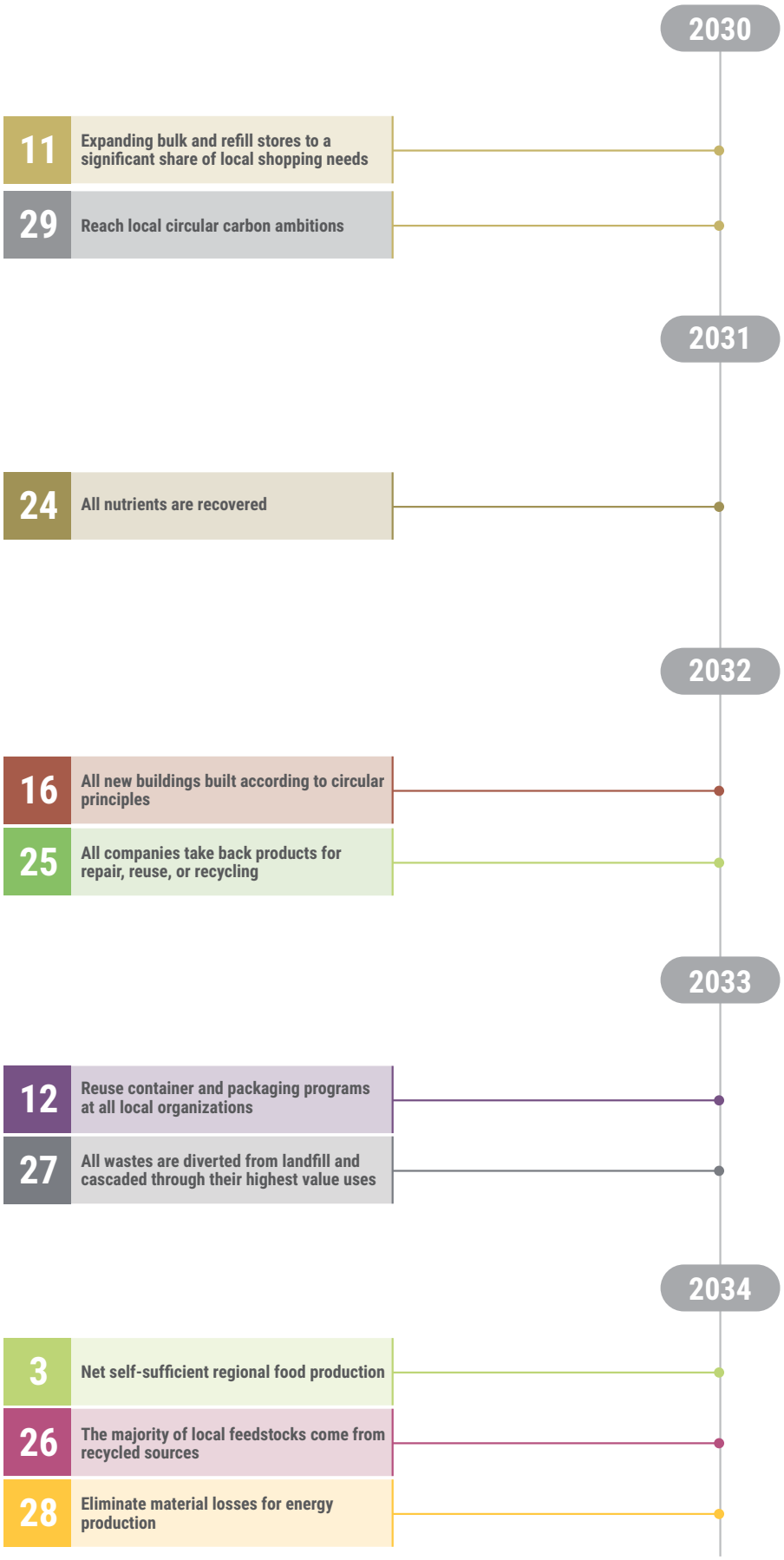
- **4** Minimize local water footprint to a sustainable level for the regional climate
- **14** Making a significant reduction in consumption through repair and reuse programs
- **23** Organic materials are all cascaded through the highest value uses

Identify ways to shift parking to free up space for other uses locally
Develop plan for circular carbon
Requiring new construction plans to include material passports
Establish a water credit score for households and businesses to incentivize consuming less water than required
Pilot wastewater separation (e.g. urine separation and phosphorus recovery) in a city building

Banning disposable, single-use products
City diverts treated wastewater for irrigation purposes

Developing a brand or certification for circular products and businesses

Require companies to take back products or pay fees that provide seed funding for repair, reuse, and recycling


2030
11
Expanding bulk and refill stores to a significant share of local shopping needs
29
Reach local circular carbon ambitions
2031
24
All nutrients are recovered
2032
16
All new buildings built according to circular principles
25
All companies take back products for repair, reuse, or recycling
2033
12
Reuse container and packaging programs at all local organizations
27
All wastes are diverted from landfill and cascaded through their highest value uses
2034
3
Net self-sufficient regional food production
26
The majority of local feedstocks come from recycled sources
28
Eliminate material losses for energy production

06

CONCLUSIONS AND NEXT STEPS

The community of Boulder is deeply connected to the environment and is therefore working hard to improve sustainability across the board. The city's targets for local emissions and waste reduction are ambitious; achieving them over such a short period will pose a monumental challenge. Adding to this is the fact that Boulder's already advanced position means an even greater challenge - small, incremental solutions won't do. Instead, the city needs to lead the way in implementing deep, systemic change through coordinated action to foster a circular economy.

Creating a circular city brings many benefits over and above emissions and waste reduction, and can support additional ambitions of the city such as building a healthy local environment, fostering a strong and innovative local economy, and establishing stronger resilience in the community. Therefore, redesigning the local economy and material system can bring holistic benefits, but it requires the city, community, and local organizations working together to achieve a shared vision.

This summary document presents only the first steps: a big picture understanding of the current state and how far we have to go, and a first vision and roadmap outlining where we are trying to get to and how. As 2019 draws to a close, the City is preparing its next steps for the coming year, when it will further engage the local community in giving body to the circular economy in Boulder, and prioritize the actions that will help achieve its zero-waste targets.

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APPENDIX

MATERIAL FLOW ANALYSIS

The material flow analysis (MFA) was made for the year 2018 using the following sources, assumptions, and calculations:

- Composition of Boulder's waste, provided in the Boulder County - Countywide Waste Composition Study by MSW Consultants (2019).
- Total tonnage of Boulder's Waste, provided in the City of Boulder's Open Data Catalog.
- Household Consumption, estimated based on the Bureau of Labor Statistics (2019) Consumer Expenditures Survey for the year 2018. These give average U.S. consumption in monetary value. These were converted to mass by factors calculated from the U.S. Department of Transportation (2018) data for the year 2017. This data provides the value and tonnage of freight transported to the state of Colorado.
- Household Food Consumption, the MFA graphic depicts a much lower level of granularity than the data behind the scenes, as a lot of categories were aggregated to fit the information in one picture. For household food consumption for example, a breakdown by food categories was used to provide more accurate outcomes in the impact assessment. The information on the breakdown of food categories was taken from the United States Department of Agriculture (2014) Food Consumption and Nutrient Intakes data set.
- Construction materials, factors were calculated for material intensity of buildings per square foot, based on the study of Ochsendorf et al. (2011) which calculates material intensity for different types of buildings in Phoenix, Arizona. These factors were applied to the square feet of newly constructed buildings in the City of Boulder, from data on construction permits in the City of Boulder's Open Data Catalog.
- Private and public sector consumption, value of demand by sector nationally based on input-output data for U.S. sectors from the Bureau of Economic Analysis (2019) for the year 2017, converted to factors per employee and business based on data from the United States Census Bureau (2017). These factors were applied to the City of Boulder based on the number of local companies and employees in specific sectors in the city, drawing on data from the Boulder Economic Council (2018) Market Profile report. Finally, these outcomes, given in value, were converted to mass by factors calculated from the U.S. Department of Transportation (2018), which provides the value and tonnage of freight transported to the state of Colorado. Data on material demands for the construction sector were left out since this was calculated separately and data on material demands for the manufacturing sector were excluded as this is very dependent on what is being manufactured and in what volumes.
- Mass flow estimation checks, where the consumption patterns of households and businesses of Boulder differ from national averages, the estimations we have made will be incorrect. As a second way to sense check that the order of magnitude of our estimations was correct, we compared outcomes from a secondary estimation method. In this method, and estimation of mass is calculated based on local tax data. The City of Boulder (2018) Sales/Use Tax Revenue Reports were used to check for any major discrepancies where there was data for similar categories of products. For example, the estimation for household vehicle consumption comes out to 7,935 tons. The public and private sector estimation comes out to 4,374 tons. If we look at the tax data, the total tons comes out to 10,321 for the city (vs. a total of 12,309 tons estimated based on U.S. average consumption data sets). We can conclude here that the outcomes are likely in the correct order of magnitude.
- Additional information on reuse programs, provided by the Center for Hard to Recycle Materials, Art Parts, and the Household Hazardous Waste Facility.

WATER, ENERGY, AND EMISSIONS FLOW ANALYSIS

The Water, Energy, and Emissions Flow Analysis was made for the year 2018 using the following sources, assumptions, and calculations:

- Energy use, water use, and water treatment, provided by a data request from the City of Boulder.
- Detailed water use breakdown, for the state of Colorado from Waskom & Neibauer (2014).
- CO_2 emissions, from the City of Boulder's 2018 greenhouse gas emissions inventory & summary report (Lotus Engineering & Sustainability, 2019).

ANALYSIS OF HOTSPOTS & OPPORTUNITIES

A lot of information on specific hotspots comes from reports, interviews, and observations made in person, from too many sources to list briefly here. However, for a few topics, we additional analysis, and the data sources and assumptions are listed here:

- Embodied CO_2 and land, given in CO_2e, mostly based on data from the lifecycle assessment database Ecoinvent (Wernet et al., 2016). Other data sources used to fill additional gaps include Kissinger et al. (2013), ICE Database V3.0 9 August 2019, Schmidt (2015), Feingold (2012), Gasol et al. (2011), Andrae et al. (2010), and the Beverage Industry Environmental Roundtable (2012).
- Greenhouse gas emissions from local sources, from the City of Boulder's 2018 greenhouse gas emissions inventory & summary report (Lotus Engineering & Sustainability, 2019).
- Value of landfilled materials, calculated on the basis of information from Boulder County's Boulder County Recycling Analysis (2015) and the Resource Conservation Advisory Board Meeting Minutes (2018).
- Emissions from landfilled materials, calculated using the EPA's WARM model.
- Per capita waste figures, U.S. average data on per capita waste by material type comes from Statista (2019) and OECD (2019).
- Nutrient cycle closure calculations, based on the two following sources: nutrients in human waste is from Rose et al. (2015), while the nutrient content of biosolids is from Sullivan, Cogger & Bary (2015).

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