CIRCULAR
ECONOMY
IN CITIES

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URBAN MOBILITY SYSTEM

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URBAN MOBILITY SYSTEM

Mobility is a vital part of a thriving urban economy, but mobility solutions that do not take account of economic, environmental and societal impacts, can also be detrimental to urban life. Current linear practices in urban mobility, such as a high dependence on individual car ownership and fossil fuels, have created high levels of congestion leading to wasted time and lost productivity, as well as pollution, noise, heat-island effects, and the depletion of finite resources. Dependence on individual cars in cities can also be a strain on household budgets and can lead to high amounts of urban land devoted to parking. With urbanisation and the demand for urban freight rapidly increasing, the need for more effective urban mobility solutions are pressing. Given this, circular economy principles to design out waste and pollution, keep materials in use and at value, and regenerate natural systems provide the much-needed solution.

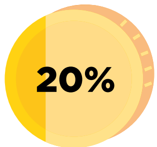
DRIVERS FOR CHANGE

Congestion costs **2–5%** of global GDP annually in lost time, wasted fuel, and increased cost of doing business[1]

As much as **50%** of European inner-city land is devoted to roads and parking; but, even in rush hour, cars use only **10%** of urban roads[2]

92%

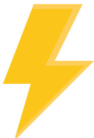
On average, European cars are parked **92%** of the time and when in use only **1.5 out of 5** seats are occupied[3]



20% of average European and US household gross income is spent on car ownership[4]

In India, electricity to power street lighting and maintenance costs can account for **5–10%** of municipal budgets in large cities and up to **20%** in smaller cities[5]

90% of urban residents in Europe are exposed to harmful levels of air pollution[6]



Urban transport accounts for **20–50%** of cities' final energy consumption (excluding industry) and based on current trends this consumption will experience the highest growth[7]

Freight accounts for **20%** of urban traffic, and it leads to **50%** of urban road transport CO^2 emissions and **60%** of urban road transport air pollution[8]

> **"...circular economy opportunities could reduce the total cost of access to mobility by CNY 12.6 trillion (USD 2 trillion) in 2030: an improvement of 36% over the current development path. (...) Furthermore, implementing circular economy opportunities would result in a decrease in consumption of non-renewable resources, including fossil fuels, by 49% in 2030 and 71% in 2040."**
>
> Ellen MacArthur Foundation, The Circular Economy Opportunity for Urban and Industrial Innovation in China (2018)

HOW CAN A CIRCULAR ECONOMY APPROACH ADDRESS THESE CHALLENGES?

A circular urban mobility system focuses on effectively accommodating the user's mobility needs by diversifying modes of transport. Core benefits of a circular economy development path include reducing virgin material consumption from the mobility sector, eliminating waste and pollution, maximising infrastructure and vehicle utilisation, and lowering use and operation costs.

Now is the time to act. As urbanisation rapidly increases, urban mobility systems are under increased pressure and without a change of approach, will result in more costly congestion, and health issues. By harnessing and combining opportunities such as compact urban development, digital optimisation of mobility services, new manufacturing and construction techniques, new business models, and developments such as remote working, a new urban mobility system can be shaped that supports the overall economic, environmental, and social prosperity of the city.

SUMMARY

PHASE	EXAMPLES OF CIRCULAR ECONOMY OPPORTUNITY
p PLANNING	1. Compact city development for effective mobility 2. Urban freight strategies for effective reverse logistics and resource flows 3. Infrastructure for zero-emission vehicles and energy storage 4. Using big data solutions to optimise mobility systems
d DESIGNING	1. Designing vehicles for adaptable and shared use 2. Design for zero-emission transport vehicles and energy grids 3. Designing transport infrastructure for adaptable use 4. Designing regenerative and energy positive, mobility infrastructure
m MAKING	1. Sourcing infrastructure materials strategically 2. Manufacturing vehicles using resource-effective techniques 3. Building infrastructure with new construction techniques
a ACCESSING	1. Alternatives solutions that reduce transport needs 2. Active and low-impact mobility solutions 3. Multimodal transport as an integrated service 4. Optimising freight capacity through shared solutions and distributed centres
o OPERATING AND MAINTAINING	1. Minimising trip length, duration, and operational energy use via digital solutions 2. Mobility assets operated and maintained in new business models 3. Refurbishing and repairing vehicles to extend material cycles 4. New techniques for infrastructure operation and maintenance

SUMMARY

PHASE	EXAMPLES OF BENEFITS	
PLANNING	**Reducing crime**: In Kansas City, crime in Kessler Park dropped by 74% the year that 2.6 miles around it were turned car-free on weekends.[9]	COMMUNITY AND SOCIAL PROSPERITY
DESIGNING	**Reducing the total urban car fleet:** A study suggests that the introduction of shared autonomous vehicles (AV) integrated with mass-transit could meet urban mobility needs while removing 9 out of 10 cars in European cities and freeing up a significant amount of parking space for alternative land use.[10]	RESOURCE USE
MAKING	**Increasing skilled labour requirements:** Remanufacturing of vehicle parts can increase skilled labour requirements by up to 120%.[11]	JOBS, SKILLS, AND INNOVATION
ACCESSING	**Gaining time and saving costs:** In the US, employers can save over USD 11,000 per half-time telecommuter per year while half-time telecommuters gain back 11 days a year – time they would have otherwise spent commuting.[12]	ECONOMIC PRODUCTIVITY
OPERATING AND MAINTAINING	**Reducing light energy CO^2 emissions:** Replacing outdoor lighting in the US with LED lighting can reduce the impact of carbon emissions by the equivalent to taking 8.5 million cars off the roads for a year.[13]	HEALTH AND ENVIRONMENT

ENDNOTES

1 UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013) p. 8; McKinsey *Urban mobility at a tipping point* (September 2015),

2 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015), p. 18

3 Ibid., p. 54

4 Ibid., p. 54; A. Stutzer and B. S. Frey, *Stress that doesn't pay: the commuting paradox* (2004), p. 4,

5 World Bank, *LED street lighting: unburdening our cities*, (7 August 2017),

6 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015), p. 54

7 B. Lefèvre, *Urban transport energy consumption: determinants and strategies for its reduction. An analysis of the literature*, surveys and perspectives integrating environment and society (2009)

8 P. Rode *et al.*, *Accessibility in cities: transport and urban form*, LSECities (2014), p. 7; UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013), pp. 58, 68

9 Arup, *Cities alive: towards a walking world* (2016), p. 41

10 OECD, *Urban mobility system upgrade, how shared self-driving cars could change city traffic* (2015), p. 5,

11 International Resource Panel/the UN Environment, *Re-defining value: the manufacturing revolution – summary for policymakers* (2018), p. 25,

12 Global Workforce Analytics and *Flexjobs: 2017 state of telecommuting in the U.S. employee workforce* (2017), p. 3

13 World Bank, *LED street lighting: unburdening our cities*, (7 August 2017)

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PLANNING EFFECTIVE TRANSPORT OF PEOPLE, PRODUCTS AND MATERIALS

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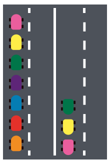
Mobility is a key urban priority. It is central to how a city operates, and has a significant impact on quality of life, the local environment, and resource consumption. Effective urban mobility systems can be enabled by accommodating all modes of transport. The system can be further optimised by integrating mobility planning with the spatial planning while considering how products and services are produced and accessed.

CASE FOR CHANGE



2–5% of global GDP is lost due to congestion, by measures such as in lost time, wasted fuel, and increased cost of doing business[1]

50%

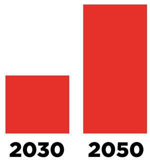
As much as **50%** of European inner-city land is devoted to roads and parking; but, even at rush hour, cars use only **10%** of urban roads[2]

90% of air pollution in cities is caused by vehicle emissions[3]

60% of air pollution from urban road transport comes from freight[4]

86%

86% of delivery vehicle parking is illegal because of a lack of loading spaces[5]



In a business-as-usual scenario, total motorised mobility in cities will rise by **42%** by 2030 and **94%** by 2050 compared to 2015[6]

> **"The rationalisation of goods transport by pooling spaces and vehicles, as well as by linking up the territory, is essential for the growth of the circular economy."**
>
> Mairie de Paris, Paris Circular Economy Plan (2017)

EXAMPLES OF CIRCULAR ECONOMY OPPORTUNITIES

Compact city development for effective mobility

As outlined in *Buildings: Planning*, urban density and land-use patterns heavily determine transport habits. Compact cities are transit-oriented and dense with mixed-use neighbourhoods. These attributes create favourable conditions for both shared mobility options (e.g. buses, trams, ride-shares) and active mobility options (e.g. walking, bicycling), which subsequently have a broad range of benefits. In contrast, low-density, sprawling cities require increased mobility infrastructure and typically this sees a growth in the number of vehhicles in use, which results in more congestion, energy and resource consumption, and pollution.[7]

Urban freight strategies for effective reverse logistics and resource flows

In a circular economy, where goods and materials will increasingly circulate locally, effective urban freight and logistics are key. The development of urban freight strategies by city governments is essential to enable the provision of such services in a way that also supports parallel priorities for air quality, noise, waste, and economic growth.[8] Reaching beyond vehicles and infrastructure, these strategies can also plan for and support new practices and technologies e.g., the virtualisation of products (such as, music streaming), digital manufacturing, and underground vacuum (pneumatic) waste collection and sorting systems. This approach will help reduce the overall need for urban freight transport.

Infrastructure for zero-emission vehicles and energy storage

By 2022, more than 10% of urban vehicles will be electric or hybrids, which will require the rollout of supporting infrastructure such as charging points and stations.[9] The electrification of urban fleets should go hand-in-hand with a transition to renewable energy to reap the full benefits. Vehicle-to-grid infrastructure (or bi-directional chargers) allowing energy stored in vehicles to support local grids, could also be a part of the infrastructure transition. Re-use and recycling of EV batteries is a further element for consideration, keeping batteries in use, at their highest value, and avoiding pollution.[10] (See *City Case Study: Shenzhen*).

Using big data solutions to optimise mobility systems

One of the main advantages of urban mobility planning today is the availability of data and complex data-processing technology. Transport agencies and operators can use this wealth of data (such as commuter habits or the impact of events on transport) to inform the management, planning, and operation of a city's transport networks over time. Real-time data solutions can also be used to monitor and instantly regulate traffic flows in the form of dynamic pricing, route planning, and parking space allocation.[11]

EXAMPLES OF WHAT URBAN POLICYMAKERS CAN DO

Urban planning pertaining to transport, infrastructure and buildings, is very often within the remit of city governments. City governments therefore have a significant opportunity to reduce travel and freight distances through compact city development. Integrated **roadmaps and strategies** for all urban mobility, including freight, is also proving a key lever for ensuring effective logistics and resource flows. **Convening and partnering** with key stakeholders can lead to new solutions and innovations that support better asset use, such as battery reuse or big data solutions. Through **public procurement**, city governments can encourage zero-emission vehicles to spur innovation and improve the local environment. City data on urban traffic flows can provide valuable information for the identification of circular economy opportunities in urban **asset management** practices.

To explore further see **Policy Levers**

EXAMPLES OF LINKS TO OTHER SYSTEMS AND PHASES

Mobility: Designing Urban mobility plans can be influenced by and can influence vehicle and infrastructure design. For example, an integrated mobility plan that works to reduce heavy road freight deliveries can support the design of lighter road vehicles suitable for cities.

Products: Accessing An effective local products system is dependent on well-functioning delivery and collection services. Aligning freight strategies with the expansion of circular economy business models can be crucial.

RELEVANT CASE EXAMPLES

London's Walking Action Plan

By 2030, congestion is projected to cost London GBP 9.3 billion a year. To counter this, the city is rolling out an extensive transport plan, which includes a dedicated walking action plan aimed at adding 1 million additional walking trips a day. The city will invest GBP 2.2 billion to redesign streets, install better signposting and maps, add more pedestrian crossings, as well as improve public transport. Analysis shows that a walkable London is significantly more land-use efficient, can save up to GBP 1.6 billion in public healthcare costs, increase retail sales, reduce emissions, and increase social cohesion and living conditions.[12]

Paris' logistics hotels and inner-city green freight

Paris is bringing logistics facilities back into the city with the use of so-called 'logistics hotels' in high-density areas. These urban hotels help to reduce heavy vehicle use and the associated negative impacts, such as emissions and noise, while increasing the productivity of the delivery services. Parcels from suburban logistics centres are pooled at the 'logistics hotels' via freight train services or a limited number of larger delivery shuttle-trucks. From there deliveries are made in smaller, lower-emission vehicles such as electric tricycles that can carry up to 180 kg. The space in these 'logistics hotels' is rented out by the city at a favourable rate, but requires delivery firms to use low-emission transport modes.[13]

Reversing car-centric mobility in São Paulo

The city's 2014 urban masterplan includes a focus on the urban mobility system to expand public and active transport modes. The intention is for the measures in the plan to help increase the number of residents living near public transport from 25% in 2015 to 70% in 2025. The city allocated 30% of urban development funds towards this effort. The masterplan aims to unlock economic, societal, and environmental opportunities including supporting the provision of more affordable housing and improving economic opportunities for urban residents.[14]

Open data improves public, private, and active transport in London

With over 31 million journeys made in London every day, Transport for London (TfL) chollects vast amounts of anonymised data about how people, vehicles, and public transport move across its networks.[15] Through big data analytics, TfL are working on everything from optimising public transport lines, improving pedestrian conditions, monitoring air pollution, predicting changing transport patterns, supporting electric vehicle use, and decreasing road traffic accidents. The data is also publicly available to spur innovative solutions to the city's transport challenges. Almost 700 apps have been developed so far which are regularly used by over 40% of Londoners. In 2017, it was estimated that the release of TfL open data cost GBP 1 million, and generated annual economic benefits and savings of up to GBP 130 millions for travellers, the city, and TfL itself. Furthermore, the open data initiative directly supports around 500 new jobs, and indirectly another 230 jobs in the supply chain and the wider economy.[16]

Stockholm's integrated freight strategy

Stockholm has developed a dedicated freight strategy as one of six thematic plans that together constitute the city's mobility strategy. The plan has four objectives: to enable more reliable delivery times, facilitate the effective use of commercial freight vehicles, promote the use of clean vehicles, and advance the freight delivery system through collaborations between the city and other stakeholders. Concrete activities include improving possibilities for off-peak transport, increasing the use of waterways, increasing consolidation of logistics solutions and continuously building an understanding of how to improve the system through cross sector dialogue and data gathering.[8]

EXAMPLES OF BENEFITS

JOBS, SKILLS, AND INNOVATION

Creating jobs through public transport investment

The economic benefits of public transport investment include both direct job creation and indirect support for manufacturing, construction, and other economic activities. An investment of USD 1 billion in public transportation supports 36,000 local jobs in the US.[17]

Accessing employment

In Washington D.C., residents living in highly walkable areas can access 15–21% more local jobs, while also having better access to bus lines and parks than residents living in less walkable areas.[18]

HEALTH AND ENVIRONMENT

Reducing CO^2 emissions and pollution from cars

A car ban in central Pontevedra in Spain resulted in a 70% reduction in CO^2 emissions and less pollution.[19]

Reducing emissions from alternative freight solutions

By saving time and mileage, new urban freight delivery solutions can cut vehicle emissions by as much as 70%.[20]

Reducing obesity risk

Increasing levels of walkability in neighbourhoods decreases the risks of excess weight. A US study found that walking to work could decrease the risk of obesity by almost 10%.[21]

ECONOMIC PRODUCTIVITY

Reducing movement of trucks, storage, and costs

Underground pneumatic collection of household and commercial waste in the Jumeirah Beach Residence, Dubai, has reduced waste collection movement of trucks by 90%, space required for in building waste storage by 74%, and the cost of waste collection by 60%. Reductions have also been seen where they system has been retrofitted, such as in Bergen.[22]

Strengthening local economy

Pedestrianisation and a ban on cars in central Pontevedra in Spain resulted in increased sales in local retail stores and attracted approximately 12,000 new inhabitants to the city.[23]

Increasing freight efficiency

Redevelopment of the Southern Industrial Area (SIA) in Sydney into a genuine mixed-use area and relocation of some services could create regional freight efficiencies worth around AUD 6.5 million a year. This benefit comes from bringing supply chains closer together.[24]

Reducing costs and mileage

By using urban consolidation centres, companies could save costs up to 25% per parcel delivery and reduce delivery-related mileage by up to 45%.[25]

Positive return on active transport investment

In Amsterdam, the return on investment of improved bicycle infrastructure was estimated to be 1.5:1 while similar calculations for Delhi and Bogotá estimated the ratio to be 20:1 and 7:1 respectively.[26]

COMMUNITY AND SOCIAL PROSPERITY

Increasing personal mobility

Compact development and urban mobility planning in Curitiba has enhanced the affordability of public transport making it possible for the average low-income family to spend only around 10% of its income on transport, which is comparatively low in Brazil.[27]

Reducing crime

In Kansas City, crime in Kessler Park dropped by 74% in the year that the 2.6 miles around it were designated a car-free zone on weekends.[28]

Increasing social cohesiveness and quality of life

Empirical studies confirm lower levels of traffic in residential areas increase people's quality of life and strengthen the local community. For example, people on low-traffic streets have more friends and acquaintances from the same street than people living in areas of higher traffic.[29]

Revitalising designated areas

By restricting vehicle use in identified road grids (superblocks) within Barcelona, 60% of the land that has to date been dedicated to cars, is being turned into 'citizen spaces' leading to the revitalisation of the local area.[30]

RESOURCE USE

Reducing resource use

Urban form and spatial structure are strongly related to resource use. Compact city development can:

- Reduce the (relative) need for new urban land
- Reduce energy use for transportation by reducing distances and encourage use of public transport
- Increase the efficiency of infrastructure in general and contribute to a reduction in resource consumption (e.g., in infrastructure construction, where fewer metres of infrastructure are necessary to supply the same number of users)[31]

Increasing land-use efficiency

Through changes such as shifting land-use patterns, taking advantage of inner-city vacant land, and promoting compact urban growth, land use can be reduced by as much as 75% compared with a sprawl scenario.[32]

Reducing delivery vehicle numbers

In densely populated cities in developed countries, implementing freight measures such as consolidation centres, load pooling, autonomous electric vehicles, parcel lockers and bike couriers, could lead to a third fewer vehicles on the road due to more efficient routing and fewer failed deliveries, as well as reduced delivery costs per parcel of 35%.[33]

Balancing the electricity system

When connected to the electricity grid, electric vehicle batteries could store power when generation is high and return it to the grid when use is high. Helping balance supply and demand in this way can reduce the amount of power generation capacity needed.[34]

ENDNOTES

1 UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013) p. 8; McKinsey *Urban mobility at a tipping point* (September 2015)

2 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015) p. 18

3 Arup, *Cities alive: towards a walking world* (2016) p. 72

4 P. Rode *et al.*, *Accessibility in cities: transport and urban form*, LSECities (2014) p. 7; UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013) pp. 58, 68

5 S. Hohl, *Presentation: commercial traffic 2.0 – analysis and recommendations of delivery strategies for the CEP industry in urban areas*, Frankfurt University of Applied Sciences (2017)

6 OECD/ITF, *ITF transport outlook 2017* (2017) p. 138

7 UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013)

8 City of Stockholm, *Förslag till handlingsplan för godstrafik i Stockholms stad* (2018), T. Mourey, *Stockholm makes urban freight an integrated part of its mobility plan* (Sweden), Eltis (11 April 2017)

9 McKinsey, *Urban mobility at a tipping point* (2018)

10 Ellen MacArthur Foundation, *The circular economy opportunity for urban and industrial innovation in China* (2018) p. 65; Johan Cruijff ArenaA, *Amsterdam Arena more energy efficient with battery storage* (November 30 2016)

11 Deloitte, Assessing the value of TfL's open data and digital partnerships (2017)

12 Transport for London, *Walking action plan* (2018) pp. 12, 80; City of London, *Traffic in the City in 2018* (2018) p. 20, City of London, Traffic in the City in 2018 (2018)

13 IFSTTAR, *What is the future of urban logistics?* (2013) p. 9, 10

14 City of São Paulo, *City of São Paulo Strategic Master Plan* (2014); World Resources Institute Brasil, *Study shows how São Paulo could increase access to quality public transport for 70% of the population,* wricidades.org (13 September 2016)

15 For example, data is collected through electronic ticketing (Oyster), public wi-fi, digital bus tracking (iBus), cameras, congestion charge etc. Transport for London, *Access your data*

16 R. Sweeney/Transport for London, *Opening data fully to improve London's transport network*, Intelligent Transport (26 February 2018); Deloitte, *Assessing the value of TfL's open data and digital partnerships* (2017); Transport for London, *Our open data*, tfl.gov.uk (n.d.)

17 UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013) p. 24

18 Brookings, *Walk this way: the economic promise of walkable places in Metropolitan Washington, D.C.* (2012)

19 S. Burgen, '*For me, this is paradise': life in the Spanish city that banned cars,* The Guardian (18 September 2018)

20 McKinsey, *Urban commercial transport and the future of mobility* (September 2017)

21 Ken R. Smith *et al.*, *Walkability and Body Mass Index*, American Journal of Preventive Medicine (2008)

22 ENVAC, *Jumeirah Beach Residence*, envacgroup.com

23 S. Burgen, '*For me, this is paradise': life in the Spanish city that banned cars,* The Guardian (18 September 2018)

24 Deloitte, *The benefits of mixed use in the Southern Industrial Area* (2015) p. ii

25 McKinsey, *Urban commercial transport and the future of mobility* (September 2017)

26 UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013) p. 20

27 Ibid., p. 114

28 Arup, *Cities alive: towards a walking world* (2016) p. 41

29 J, Hart, *Driven to excess: impacts of motor vehicles on the quality of life of residents of three streets in Bristol UK* (2011)

30 M. Bausells, *Superblocks to the rescue: Barcelona's plan to give streets back to residents*, The Guardian (17 May 2016)

31 C. Fertner and J. Grosse, *Compact and resource efficient cities? Synergies and trade-offs in European cities*, European Spatial Research and Policy (2016) pp. 69–73

32 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015) p. 86

33 McKinsey, *Urban commercial transport and the future of mobility* (September 2017)

34 M. Brenna *et al.*, *Synergy between renewable sources and electric vehicles for energy integration in distribution systems*, IEEE (2012) p. 2

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DESIGNING MOBILITY ASSETS FOR COMPONENT AND MATERIAL RECIRCULATION

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The design of mobility assets – from vehicles to infrastructure – is key to reaping the benefits of a circular economy transition. Decisions made at the design stage of an asset strongly determine whether waste and pollution are designed out of the system, and whether the asset and the materials in it can be kept in use at their highest value. The design of mobility assets also has an impact on the number of vehicles on the roads, how easily vehicles can be adapted for variable use, whether mobility assets can support the urban energy system, and what type of materials they can be made of.

CASE FOR CHANGE

In Europe, only **1.5 out of 5 seats** are typically occupied in a car during use[1]

Only **10%** of roads are used during rush hour in Europe[2]

90%

90% of urban residents in Europe are exposed to harmful levels of air pollution[3]

50% of European inner-city land is paved for roads and parking leading to higher temperatures and higher risk of flooding[4]

One heavily loaded truck can inflict as much road damage as **10,000** passing light-duty vehicles[5]

EXAMPLES OF CIRCULAR ECONOMY OPPORTUNITIES

Designing vehicles for adaptable and shared use

Designing vehicles of all types for maximum use potential and the ability to remanufacture is important in order to get the most out of the materials used. Modularity, in which parts can be swapped in and out, and/or space in the vehicle can be reconfigured, can enable longer use while responding to the user's needs for changes and repair.[6] Flexible interiors in freight vehicles can be designed to support the simultaneous delivery and collection of goods and recyclables. In such flexible interiors, different loads are separated in sections that can shrink or expand, which maximises the usage of vehicle capacity.[7] Vehicle automation technology can be used to support vehicle sharing and mobility-as-a-service schemes (MaaS) (see *Mobility: Accessing*).

Designing for zero-emission transport vehicles and energy grids

Designing vehicles to use renewable energy is an important measure to reduce pollution in cities and support a shift away from finite energy resources. In addition, electric vehicles and fleets in cities can support the urban energy grid via battery energy storage (see also *Mobility: Planning*), while existing conventional vehicles can switch to biofuel made from by-products with low conversion costs. Developments in zero-emission fuel-cell technology also have the potential to decrease the negative impacts of urban mass-transit vehicles.[8]

Designing transport infrastructure for adaptable use

Several permanent or flexible solutions can be applied to make better use of urban land that is used for mobility. An example includes dynamic street-use restrictions which promote specific transport modes at certain times of day (e.g., prioritising road space for bikes indicated by LED lights in the road, or freight-lane restrictions). Simple and low-cost design interventions such as moveable street furniture (e.g., moving a potted plant or a bench onto the road) can also indicate a temporary change in the use of the road.[9]

Designing regenerative, energy-positive mobility infrastructure

In cities, the design of mobility infrastructure can support the regeneration of natural systems and contribute to energy production. Permeable pavements can allow rainwater to filter through, helping cities to manage stormwater, reduce soil and water pollution, and restore groundwater stocks.[10] By adding lighter, reflective colours to pavements, cities can be naturally cooled.[11] More emerging technologies and designs are also being trialled; in Jinan in China a 1 km ring road paved with solar panels generates around 1 million kWh a year;[12] in London, a street generates electricity when people walk on it while customised paint purifies the air;[13] and London's new Crossrail is designed to capture wind energy from passing trains.[14]

RELEVANT CASE EXAMPLES

Circular vehicle design with circular business models

Open Motors provide modular, locally assembled, electric, and self-driving vehicles that are designed for MaaS systems. The service involves its customers in the designing and assembly of customised fleet vehicles. Customers are able to achieve their designs in half the time and at a sixth of the cost of a 'regular vehicle'. The modular design allows for direct replacement of broken or outdated individual components, enabling fleets to last 10 times longer. The vehicles can be shipped in component crates and assembled locally in a simple workshop or microfactory. This process can lower environmental impact, create local jobs, and decrease import taxes and assembly costs.[15] Another innovative example of circular vehicle design is Riversimple's Rasa. Rasa is a hydrogen fuel-cell powered car. The chassis is made of very lightweight fibre composites and weighs less than 40 kg. To fully realise the opportunities of this new design, Riversimple uses a distributed manufacturing model and maintains ownership of the vehicle by selling access to it in a circular service-based ownership package which includes use-right of the car, maintenance, insurance, and fuel.[16] See *Products: Making for more about distributed manufacturing.*

Dynamic road use in Copenhagen and Barcelona

In Denmark, Copenhagen is experimenting with intelligent LED lights in the road that divide the street into dynamic lanes that signal which form of transport has priority on the road, and when. For example, the cycling tracks can be widened during morning rush hour and then contracted when there are more pedestrians and fewer cyclists. By letting the street follow the natural rhythm of the city and not vice versa, the city expects to improve transport flows and revitalise certain areas.[17] A similar scheme has been implemented in Barcelona. Here, six boulevards alternate between restricting general traffic, freight, and residential parking while LED lights and variable road signs inform drivers of the 'rules of the road' in real time.[18]

Flood proofing and smog-eating streets in Chicago

In the City of Chicago, 65% of open space is paved and heavy rainfall in the area exacerbates the issues of flooding and water pollution. Through a range of new pavement projects, the city is addressing these issues and, at the same time reducing air pollution, the heat-island effect, and waste production, and improving walking and biking facilities. For example, alleys and sidewalks are paved with a permeable surface, which includes 30% recycled content. Some streets also use photocatalytic cement which 'eats' air pollutants through a chemical process.[19]

EXAMPLES OF WHAT URBAN POLICYMAKERS CAN DO

Infrastructure **financing** can be an important focus for city governments and improved in **partnership** with others. By implementing circular economy principles in **public procurement** specifications, city governments can incentivise better designs of roads, bridges, and publicly owned vehicle fleets. Some cities also have the authority to restrict the use of polluting vehicles through **fiscal measures** (taxes, charges) or **regulation** (bans, zoning) which also create market incentives to further vehicle design developments.[20]

To explore further see **Policy Levers**

EXAMPLES OF LINKS TO OTHER SYSTEMS AND PHASES

Building: Planning and Mobility: Planning Compact city development can be a key opportunity to free up land used for transport and increase utilisation and cost effectiveness of urban mobility infrastructure. Subsequently it can also reduce the need for additional infrastructure by countering urban sprawl.

Mobility: Making The phases of designing and making overlap and are interconnected, increasingly so when the design phase takes material sourcing, manufacturing, and construction methods into account from the outset.

Mobility: Operating and Maintaining Vehicle and infrastructure design will have a significant impact on the maintenance and repairability of mobility assets and components.

Products: All The way the products system works in cities, from planning, designing, and making to accessing, operating, and maintaining is strongly linked to how the mobility system is planned and designed.

EXAMPLES OF BENEFITS

ECONOMIC PRODUCTIVITY

Reducing remanufacturing costs

Designing vehicle parts to be remanufactured can reduce the cost of remanufactured vehicles by 30–50%.[21]

Reducing maintenance costs

Maintenance costs of electric vehicles can be 50–70% less than internal combustion engine vehicles as they do not require transmission fluid, engine tune-ups or oil changes, and experience dramatically less brake wear due to regenerative braking.[22]

Reducing public spending

The electrification of Shenzhen's 16,000 buses resulted in 70% savings in fuel costs.[23]

Increasing road-use efficiency

With sufficient take-up and integrated implementation, autonomous vehicles could close the space between cars (1.5 metres versus 3–4 car lengths today), reduce congestion, and improve road use.[24]

RESOURCE USE

Reducing urban car fleets

And OECD study estimates, that the introduction of shared autonomous vehicles integrated with mass-transit could, in theory remove 9 out of 10 cars in European cities and free up a significant amount of parking space.[25]

Substituting fossil fuels

A transition to locally produced biofuels for publicly owned heavy vehicles in the Central Denmark Region led to the substitution of 11 million litres of diesel annually.[26]

HEALTH AND ENVIRONMENT

Reducing particulate emissions

Electrification of Shenzhen's 16,000 buses was a key factor in meeting the city's air quality goals and reducing the annual number of smoggy days from 115 in 2010 to 35 in 2015.[27]

Reducing CO^2 emissions

A transition to locally produced biogas (from manure and agricultural by-products as well as industrial ones) for publicly owned heavy vehicles in the Central Denmark Region led to a reduction of 26,700 tonnes of CO^2 annually.[28]

Reducing soil and groundwater pollution

Studies have seen permeable asphalts, concretes, and pavers remove up to 99% of some pollutants (such as metal, oils, and bacteria) from infiltrated stormwater – preventing those toxins from entering the groundwater or stormwater system. Average run-off reduction from porous pavements varies between 50% and 93%.[29]

Reducing accidents

With sufficient penetration and integrated implementation with the expansion of public transport, autonomous vehicles can cut accidents by up to 90%.[30]

Countering urban heat-island effect

Reflective pavements can reduce temperatures by up to 20°C.[31]

JOBS, SKILLS, AND INNOVATION

Creating jobs

A transition to locally produced biogas (rom manure, agricultural, and industrial by-products) for publicly owned heavy vehicles in the Central Denmark Region has led to approximately 100 new jobs developing the required infrastructure.[32]

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ENDNOTES

1 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015) p. 54

2 Ibid., p. 12

3 Ibid., p. 54

4 Ibid., p. 12, Arup, *Cities alive: towards a walking world* (2016) p. 74

5 UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013) p. 9

6 N. Hitti, *Mercedes-Benz unveils modular concept vehicle that transforms from car to van*, Dezeen (12 September 2018)

7 DHL, *Fair and responsible logistics: a DHL perspective on how to create lasting competitive advantage* (2015) p. 23

8 Ellen MacArthur Foundation, *The circular economy opportunity for urban and industrial innovation in China* (2018) p. 65; Ellen MacArthur Foundation, *Circular economy in India: rethinking growth for long-term prosperity* (2016) p. 54; Alstom, *World premiere: Alstom's hydrogen trains enter passenger service in Lower Saxony* (16 September 2018)

9 See initiatives in Copenhagen, Barcelona, and the Netherlands: City of Copenhagen, *Good, better, best: The City of Copenhagen's Bicycle Strategy 2011–2025* (2011) p. 15; Streetfilms, *Barcelona's superblocks: change the grid, change your neighborhood* (2018); Transportation Policy Research Centre, *Dynamic truck restrictions*

10 While permeable pavement often is too porous for high-speed traffic, it can be used on streets designed for lighter and slower traffic.

11 H. Li *et al.*, *Corrigendum: the use of reflective and permeable pavements as a potential practice for heat island mitigation and stormwater management* (2013) p. 2; K. Smale, *Permeable pavement made with recycled carbon fibre*, New Civil Engineer (5 March 2018), City of Chicago, *Presentation: Chicago's sustainable Streets pilot project*; Arup, *Cities alive: rethinking green infrastructure* (2014) p. 64

12 Xinhua, *China's solar expressway meets light of* day (28 December 2017)

13 P. Caughill, *Energy-generating pavement just became a reality in London*, Futurism (29 June 2017)

14 S. Peteranderl, *Crossrail will generate energy using the wind created by trains*, Wired (13 Feb 2018)

15 Ellen MacArthur Foundation, *CE100 Member Open Motors;* OpenMotors, *Edit*

16 Riversimple

17 City of Copenhagen, *Good, better, best: the city of Copenhagen's bicycle strategy 2011–2025* (2011) p. 15

18 L. Dablanc, *City Logistics in European Cities*, IFSTTAR (2012) p. 8

19 Arup, *Cities alive: rethinking green infrastructure* (2014) p. 64, M. Boyer, *Chicago unveils the "greenest street in America" with permeable, smog-eating pavement*, Inhabitat (15 October 2012)

20 For example, Swedish cities have the autonomy to ban diesel cars and London (GB) has congestion charges directly targeting heavy vehicles and diesel cars to create low-emission zones. The Local, *Sweden gives green light for cities to ban old diesel cars* (26 March 2018); M. Discombe, *How 'congestion charges' work in other cities*, Wales Online (26 March 2018)

21 Ellen MacArthur Foundation, *The circular economy opportunity for urban and industrial innovation in China* (2018) p. 64

22 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015) p. 56

23 Ellen MacArthur Foundation, *The circular economy opportunity for urban and industrial innovation in China* (2018) p. 66; See *City Case Study: Shenzhen*

24 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015) p. 56

25 OECD, *Urban mobility system upgrade: How shared self-driving cars could change city traffic* (2015) p. 5

26 Region Midtjylland, *Roadshow om biogas til transport* (May 2016); Biopress, *Region Midtjylland vil have biogas ind i transportsektoren* (2015)

27 Ellen MacArthur Foundation, *The circular economy opportunity for urban and industrial innovation in China* (2018) p. 66

28 Region Midtjylland, *Roadshow om biogas til transport* (May 2016); Biopress, *Region Midtjylland vil have biogas ind i transportsektoren* (2015)

29 L. M. Ahiablame *et al.*, *Effectiveness of low impact development practices: literature review and suggestions for future research*, Springer Science Business Media (2016) p. 4260

30 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015) p. 56

31 European Commission, *Cool pavements to reduce urban heat islands: the state of the technology*, "Science for Environment Policy" DG Environment News Alert Service (2015)

32 Region Midtjylland, *Roadshow om biogas til transport* (May 2016); Biopress, *Region Midtjylland vil have biogas ind i transportsektoren* (2015)

CIRCULAR
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MAKING MOBILITY SYSTEMS AND ASSETS USING NEW CONSTRUCTION AND MANUFACTURING TECHNIQUES

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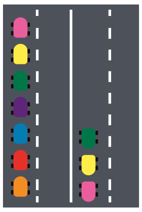
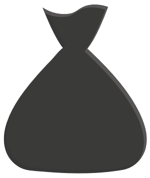
By incentivising and supporting new vehicle manufacturing and infrastructure construction techniques, cities can improve the use of resources and reduce traffic disruption. Vehicles and transport infrastructure account for significant material consumption and waste generation in cities. These negative impacts can be countered through circular economy actions that engage with infrastructure and vehicle manufacture.

CASE FOR CHANGE



13% of global resource consumption is related to mobility[1]



End-of-life vehicles constitute **8–9 million tonnes** of waste in the EU[2]

Road construction CO^2 emissions represent **5–10%** of total CO^2 emissions in the transport sector and are growing rapidly[3]

GBP 3 billion is spent by UK local authorities annually on highway construction and maintenance[4]

EXAMPLES OF CIRCULAR ECONOMY OPPORTUNITIES

Sourcing infrastructure materials strategically

Using recycled, alternative, and renewable materials in construction can boost the market for these materials and reduce virgin material demand. Ensuring that materials are reusable can eliminate landfill costs. In infrastructure projects, second generation material input is widely used. Recycled asphalt, and construction and demolition waste (CDW) used in infrastructure, has been proven to reduce construction costs while maintaining quality standards.[5] Using renewable materials such as bio-asphalt binders is also being explored; for example, using municipal organic by-products and pig manure as a substitute for traditional and more expensive fossil fuel-based asphalt binders such as bitumen.[6]

Manufacturing vehicles using resource effective techniques

Remanufacturing vehicles has the potential to create local jobs, reduce the demand for raw materials and energy, lower manufacturing costs, and close material loops.[7] Remanufacturing can be particularly promising in combination with vehicle-as-a-service models as these models incentivise prolonging the use of the assets.[8] Modular assembly and additive manufacturing of mobility assets can both increase the customisation of vehicles to a user's needs, reduce raw material requirements, and support the localisation of production which can in turn shorten the supply chain. These methods also reduce resource consumption in the manufacturing process.

Building infrastructure with new construction techniques

As with buildings, the construction of roads and bridges can be improved through new construction techniques that reduce waste and ease maintenance and repair. These include additive manufacturing, industrial construction, and building information modelling (BIM). For example, 3D printing of bridges offers a less disruptive and faster construction phase that uses fewer resources than conventional construction. Technology such as BIM can also support value chain collaboration, material tracking, and better material/component reuse down the line.[9] (See *Buildings: Making*)

RELEVANT CASE EXAMPLES

Saving road construction costs in Barnsley by using local materials

Barnsley Metropolitan Borough Council (UK) has saved GBP 13,500 by composting 450 tonnes of green waste each year and using it in highway schemes. It has saved a further GBP 60,000 in transport and landfill costs by recycling 95% of 'waste' highway materials.[10]

Locally printing and constructing mobility assets

Arevo Inc. in San Jose, California has developed a robot that can print an entire recyclable bike frame out of carbon fibre without the use of hazardous chemicals and without producing waste. The process allows a major part of the bike to be produced locally using significantly less time and energy than traditional manufacturing techniques. Due to machine affordability and the flexible nature of additive manufacturing, the business model is economically viable even with high levels of customisation and small-scale production.[11]

3D printing spare parts for trains

The Siemens Mobility RRX Rail Service Center in Dortmund runs an additive manufacturing process that reduces the time it takes to produce spare vehicle parts by 95%, while increasing the centre's self-sufficiency, and opening up more revenue streams by being able to service a greater number of low-volume orders cost-effectively and efficiently.[12]

EXAMPLES OF WHAT URBAN POLICYMAKERS CAN DO

Financial support can be an important lever when it comes to infrastructure development in cities, often in **partnership** with others. By implementing circular economy principles in **public procurement** specifications, city governments can also incentivise the use of new construction techniques and alternative, renewable, and reusable materials for roads, bridges, publicly owned vehicles, and vehicle fleets. Furthermore, by including mobility assets in waste reduction, reuse, and recycling targets in **roadmaps and strategies**, a city government can create long-term signals for the market.

To explore further see **Policy Levers**

EXAMPLES OF LINKS TO OTHER SYSTEMS AND PHASES

Mobility: Designing New construction and manufacturing techniques, and material choices, are often closely linked to decisions made in the design phase of vehicles and infrastructure. At the same time, design will need to be cognisant of new techniques.

EXAMPLES OF BENEFITS

ECONOMIC PRODUCTIVITY

Reducing construction time

Modular and offsite construction solutions helped save six months of construction time, reduce site labour by 30%, and minimise waste production on the A453 road widening project in the Midlands, UK.[13]

Reducing manufacturing time and stocks of spare parts

Additive manufacturing can reduce spare part production time by 95% and eliminate the need to stock up on spare parts as companies can print these in-house.[14]

Saving vehicle material costs

Remanufactured vehicle parts can be 30–50% less expensiveand still retain having the same levels of quality and guarantees as new parts made from virgin materials.[15]

Improving the business case while creating additional jobs and skills

While the cost of labour for remanufacturing vehicle parts may be a relatively higher share of the total production costs compared to linear manufacturing, it is typically more than offset by the relative reduction in materials, utilities, and other overheads and operating costs.[16]

JOBS, SKILLS, AND INNOVATION

Increasing skilled labour requirements

Remanufacturing of vehicle parts can increase skilled labour requirements by up to 120%.[17]

HEALTH AND ENVIRONMENT

Reducing emissions from road construction

Using recycled materials in road construction can reduce carbon emissions associated with asphalt roads by 37%, and by 28% in the case of concrete or brick roads.[18]

Minimising CO^2 emissions from vehicle parts

Remanufactured automotive engines could be produced with from 73% to 87% fewer CO^2 emissions than compared to traditional manufacturing of new engines.[19]

Minimising emissions through remanufacturing

In Michelin's truck tyre retreading plant, an estimated 60 kg of CO^2 emission is avoided each time a tyre is retreaded.[20]

COMMUNITY AND SOCIAL PROSPERITY

Including new customer segments

Lower-priced, remanufactured vehicle product options make these products more accessible to lower-income customer segments, who might not have been able to purchase them previously.[21]

RESOURCE USE

Saving material input

3D printing, also known as additive manufacturing, of machine components can reduce resource use by up to 65%.[22]

Minimising virgin material used in tyres

In Michelin's truck tyre retreading plant, 85% of a worn-out tyre is reused, saving some 30 kg of rubber and 20 kg of steel per retreaded tyre.[23]

Minimising material and energy used for vehicle parts

The remanufacturing of automotive components yields up to 88% of material savings compared to using a new product, with an associated 56% lower energy requirement.[24]

Reducing natural resource demands

Renault's remanufacturing process uses 80% less energy and 88% less water compared to the production of new parts.[25]

Recycled materials reducing demand for fuel and virgin materials

The use of recycled materials on the Burntwood Bypass in Staffordshire, UK saved nearly 200,000 miles of lorry movements, equivalent to 128,000 litres of fuel – resulting in GBP 60,000 of financial savings.[26]

ENDNOTES

1 Circle Economy, *Towards a circular economy Amsterdam* (2018)

2 European Commission, *Directive 2000/53/EC of the European Parliament and of the council on end-of life vehicles* (2000) p. 2

3 World Bank, *Greenhouse gas emissions mitigation in road construction and rehabilitation: a toolkit for developing countries* (2010) pp. 11, 13

4 WRAP, *Recycled roads* (2005) p. 5

5 European Commission, GPP in practice: recycled asphalt used for road resurfacing (n.d.); A. Molenaar, *Durable and sustainable road constructions for developing countries*, Procedia Engineering (2013)

6 Aston University, *Aston scientists pave way for greener roads made of domestic waste* (1 June 2018); E. Fini *et al.*, *Chemical characterization of biobinder from swine manure: sustainable modifier for asphalt binder* (2010)

7 Ellen MacArthur Foundation, *News: the circular economy applied to the automotive industry* (9 October 2012)

8 Ellen MacArthur Foundation, *The circular economy opportunity for urban and industrial innovation in China* (2018) p. 64; Ellen MacArthur Foundation, *Circular economy in India: rethinking growth for long-term prosperity* (2016) p. 54

9 Agence France-Presse, *World's first 3D-printed bridge opens to cyclists in Netherlands*, The Guardian (18 October 2017)

10 WRAP, *Recycled roads* (2005) p. 5

11 A. Peters, *Now you can 3D print an entire bike frame*, Fast Company (7 December 2018)

12 T. Boissonneault, *Siemens Mobility cuts manufacturing times by 95% with 3D printing at new rail service center*, 3D Printing Media Network (19 September 2018); L. Griffiths, *Siemens Mobility is 3D printing spare parts at first digital rail maintenance centre*, The Magazine for Design-to-Manufacturing Innovation (20 September 2018)

13 C. Jensen, *DFMA and the A453 road widening project: a new approach to bridge construction*, Institution of Civil Engineers (26 October 2015)

14 T. Boissonneault, *Siemens Mobility cuts manufacturing times by 95% with 3D printing at new rail service center*, 3D Printing Media Network (19 September 2018); L. Griffiths, *Siemens Mobility is 3D printing spare parts at first digital rail maintenance centre*, The Magazine for Design-to-Manufacturing Innovation (20 September 2018); Ellen MacArthur Foundation, *Brands team up to see how 3D printing can revolutionise repair*, Circulate (8 November 2018)

15 Ellen MacArthur Foundation, *The circular economy opportunity for urban and industrial innovation in China* (2018) p. 64

16 International Resource Panel/the UN Environment, *Re-defining value: the manufacturing revolution – Full report* (2018) p. 85

17 Ibid., p. 25

18 European Commission, *Green innovations could cut carbon emissions from road projects by a third*, "Science for Environment Policy" DG Environment News Alert Service (2015)

19 S.S. Yang *et al.*, *The impact of automotive product remanufacturing on environmental performance*, Elsevier B.V (2015) p. 774

20 The Society of Motor Manufacturers and Traders (SMMT), *2018 UK automotive sustainability report (2018)* p. 25

21 International Resource Panel/the UN Environment, *Re-defining value: the manufacturing revolution – summary for policymakers* (2018) p. 27

22 Siemens, *Additive manufacturing* (n.d.)

23 The Society of Motor Manufacturers and Traders (SMMT), *2018 UK automotive sustainability report (2018)* p. 25

24 European Remanufacturing Network, *Remanufacturing market study* (2015) p. 11,

25 Ellen MacArthur Foundation, *The circular economy opportunity for urban and industrial innovation in China* (2018) p. 64

26 WRAP, *Recycled roads* (2005) p. 6

CIRCULAR
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ACCESSING SHARED AND USER-CENTRIC URBAN MOBILITY SOLUTIONS EFFECTIVELY

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Getting around in cities can often be inefficient and slow. Today's dominant transport modes have also led to additional challenges, such as air pollution, greenhouse gas emissions, and noise pollution.[1] They can also be price prohibitive, exacerbating social inequalities. However, these challenges can be countered by leveraging innovative technologies and new business models. The transport of people and goods, materials and by-products is an ongoing activity in every prosperous city, and demand for transportation is only expected to increase.[2] Vehicle automation is also predicted to impact urban mobility systems.[3] However, the outcome of this transformation is entirely dependent on how these new digital solutions are applied. Today's urban mobility system is highly car-dependent, but solutions for people and goods can be diversified to include mass-transit, ridesharing, load-pooling, and low-impact vehicles – all of which can offer a broad range of benefits.

CASE FOR CHANGE

92%

On average in Europe, cars are parked **92%** of the time and when in use only **1.5 out of 5** seats are occupied[4]

In 2015, US drivers wasted **8 billion hours** stuck in traffic[5]

20%

20% of an average European and US household's gross income is spent on car ownership costs[6]

Freight tonnage moved by trucks is forecast to grow **27%** between 2016 and 2027, driven largely by the rise in e-commerce and same-day delivery demand[7]

20% of urban traffic is freight, and it accounts for **50%** of urban road transport CO^2 emissions and **60%** of urban road transport air pollution[8]

"We are required to provide residents of the Moscow agglomeration with fast, comfortable and eco-friendly transport that is a worthy alternative to a personal car, since during peak hours Moscow highways and streets are substantially overloaded at virtually all entrances into the city from the suburbs."

Maxim S. Liksutov, Deputy Mayor, Moscow (2018)

"In social terms, access to jobs, education, health services and other facilities is increased by public transport provision; these are central to social inclusion for the disadvantaged. Furthermore, public transportation also supports community cohesion by increasing the quantity and quality of interactions between people..."

UN Habitat, Planning and design for sustainable urban mobility: global report on human settlements (2013)

EXAMPLES OF CIRCULAR ECONOMY OPPORTUNITIES

Alternative solutions that reduce transport needs

Transport demand for people and goods in cities is forecast to continue increasing,[9] however some of that pressure can be alleviated. Distributed and digital manufacturing (such as 3D printing) can reduce or completely replace freight transport as products or components are made on-site/ close to their users (See *Making* worksheets in *Building*, *Products,* and *Mobility*). Conveniently located self-serve parcel lockers where the users collect or drop off parcels can also simplify last-/ first-mile freight transport.[10] Automated vacuum (pneumatic) refuse systems can substitute freight vehicles while being more space, and energy-efficient, and supporting better municipal solid waste recycling.[11] Improved internet access and teleconferencing solutions are also enabling people to work remotely, reduce overall travel needs, and gain back time by skipping the daily commute.[12]

Active and low-impact mobility solutions

Switching to active transport (walking, biking) and zero-emission and/or lighter vehicles (electric cars, cargo-bikes, scooters, minibuses) is often very compatible with cities and can generate productivity gains, better health, reduce resource demand, and minimise pollution.[13] While such opportunities exist in any city, compact city development can further amplify these benefits. (See *Buildings: Planning* and *Mobility: Planning*)

Multimodal transport as one integrated service

Mass-transit, such as metro, rail, and bus rapid transit (BRT), has the benefits of being high capacity and cost- and land-use efficient.[14] However, these modes of transport do not always cover a user's needs, as users look for greater convenience and integration with the city's broader transport system. Mobility-as-a-Service (MaaS) is a type of mobility scheme that blurs the line between public and private transport services. MaaS is characterised by using digital technology to integrate all modes of urban transport – from taxis to ride-shares, and bicycles to mass-transit and support sharing – and optimise use. MaaS schemes also aim to give users access to a diverse set of transport options that offer seamless, multimodal trip planning, dynamic pricing, sharing, e-ticketing, and payment services via one online platform.[15] With the introduction of autonomous vehicles (AVs), MaaS could also offer a platform for shared used of AVs.

Optimising freight capacity through shared solutions and distributed centres

When managing the load capacity of freight vehicles, pooling, sharing and intelligent logistics systems can maximise vehicle utilisation and minimise freight kilometres. Digital platforms that support the consolidation of freight services, for example load-pooling platforms that match freight companies with available load-capacity, support best use of space and reduce trips.[16] Crowd-delivery/collection can also achieve similar outcomes, particularly with last- or first-mile delivery.[17]

RELEVANT CASE EXAMPLES

Copenhagen: A bicycle city

In Copenhagen, around 40% of daily commutes are made by bicycle. The city's bicycling infrastructure means it is often perceived as the most convenient transport option. In addition to supporting the city's 2025 carbon neutrality target, bicycling also generates a net profit for society through increased productivity and health (EUR 228 million in 2009). To further increase bicycling rates, the city has implemented a range of initiatives, including an electric city-bicycling scheme, dedicated cargo-bicycle parking,[18] bicycling highways, and green bicycling routes creating shortcuts across the city. The regional trains also support the increased bicycle use by allowing users to bring bicycles on, free-of-charge, in specifically adapted carriages making first- and last-mile transport more convenient for longer-distance commuters.[19]

Whim: one operator for public, private, and active transport modes

In Helsinki, the West-Midlands and Antwerp, *Whim* offers access to (almost) all types of transport through an integrated MaaS scheme. Via one platform, travellers can get access to everything from bikes to cars, taxis, and public transport on either a pay-as-you-go basis or through a range of tailormade monthly subscription packages. The user enters their destination in the MaaS app and selects the preferred route of getting there, which will cover one or several modes of transport.[20]

Ride hailing as a community asset in Austin

RideAustin is a non-profit ride-hailing company specifically designed for and by the local community. It offers similar services as Uber and Lyft who left the city in 2016, but due to its small-scale and non-profit business model it manages to keep overheads down and prices low, while improving pay conditions for drivers. It is powered by donations and volunteers, predominantly from Austin's local tech community, who also provide technology support for the RideAustin app. A special donation system also allows customers to round up to the nearest dollar, donating the extra money to local charities. Two years in, the company has carried out millions of trips and raised over USD 250,000 for charities.[21]

Inner-city delivery solutions with Cubicycle

In 2017, DHL introduced the 'City Hub' in Frankfurt and Utrecht for inner-city deliveries. It uses a customised trailer to carry up to four containers attached to a single delivery vehicle, which replaces two standard delivery vehicles. Once in the city, the four containers are individually loaded onto a DHL Cubicycle – a customised electric cargo bicycle. The Cubicycles complete the last-mile inner-city delivery, and can be reloaded for outbound shipments. This enables the completion of twice as many deliveries per hour as normal vehicles, and costs DHL less than half of what a delivery van would during its lifetime.[22]

EXAMPLES OF WHAT URBAN POLICYMAKERS CAN DO

Bringing together a multimodal mobility system entails foresight and clear **roadmaps and strategies** to provide a vision and ensure effective alignment in the longer term. Such strategies can also bring together multiple levers, such as **urban planning**, that are appropriate to the city's mobility context. City governments can also partner with others, such as higher tiers of government and the private sector, to bring together the **financial support** for infrastructure changes, and amend **regulations** and **fiscal incentives,** such as those linked to specific vehicle types.

To explore further see **Policy Levers**

EXAMPLES OF LINKS TO OTHER SYSTEMS AND PHASES

Mobility: Planning There are great potential benefits from a circular economy perspective in consolidating the infrastructure that supports urban freight (such as warehouses and logistics hubs).

Mobility: Planning and Buildings: Planning Compact urban development can be a key opportunity to reduce travel distances and encourage active transport.

EXAMPLES OF BENEFITS

ECONOMIC PRODUCTIVITY

Increasing footfall and retail sales

Making streets more pedestrian friendly can boost footfall and trading by up to 40%.[23]

Reducing heavy vehicle use

Load-pooling reduces the number of heavy vehicles on the road and delivery-related mileage by up to 30%.[24]

Commercial cost savings

Reducing business and freight road travel time in the UK by 5% could produce up to GBP 2.5 billion commercial cost savings every year.[25]

Generating positive socio-economic returns

In the US, for every USD 1 invested in public transportation approximately USD 4 is generated in economic returns.[26]

Gaining time and saving costs

In the US, employers can save over USD 11,000 per half-time telecommuter per year while half-time telecommuters gain back 11 days a year – time they would have otherwise spent commuting.[27]

JOBS, SKILLS, AND INNOVATION

Increasing creative output

A person's creative output increases by an average of 60% when walking indoors or outdoors.[28]

Increasing employment

Data from more than 300 metropolitan areas across the US showed that for every four seats added to railway carriages and buses per 1,000 residents in the city centre, there was a 19% increase in the number of employees per square mile. Adding 85 rail miles delivered a further 7% increase.[29]

Increasing wages

Doubling mass-transit seat capacity generated wage increases ranging from 1.1% to 1.8% per metropolitan area in the US.[30]

HEALTH AND ENVIRONMENT

Reducing CO^2 emission with mass transit

Heavy rail transit, such as subways and metros, produce around 76% less in CO^2 emissions per passenger mile than an average single-occupancy vehicle. Light rail systems produce 62% less and bus transit produces 33% less. The more passengers that are riding a bus or train, the lower the emissions per passenger mile.[31]

Reducing CO^2 emissions with telecommuting

In the US, telecommuters reduce greenhouse gas emissions by the equivalent of taking over 600,000 cars off the road for a year. If the work-at-home workforce expanded to include those who could and wanted to telecommute *half of the time*, the GHG savings would equate to taking 10 million cars off the road.[32]

Improving health statistics

Cycling to work can reduce the risk of mortality by 39%.[33]

Increasing active mobility and health

If every Londoner walked or cycled for 20 minutes a day, it would save the National Healthcare System (NHS) GBP 1.7 billion in treatment costs over the next 25 years. This includes an estimated 85,000 fewer Londoners being treated for hip fractures, 19,200 fewer suffering from dementia, and 18,800 fewer suffering from depression.[34]

COMMUNITY AND SOCIAL PROSPERITY

Supporting inclusive access

Mass-transit such as metro, rail and bus rapid transit (BRT) is cost-efficient, which supports low-income groups to access services and work.[35]

Saving household mobility costs

In the US, a household can save more than USD 10,000 by taking public transportation and living with one fewer car per household.[36]

RESOURCE USE

Reducing the total urban car fleet

A study suggests that the introduction of shared autonomous vehicles (AVs) integrated with mass-transit could, in theory, meet urban mobility needs while removing 9 out of 10 cars in European cities and freeing up a significant amount of parking space for alternative land use.[37]

Reducing fuel consumption through public transport

By reducing vehicle miles travelled, public transportation in the US reduced energy use in 2008 by the equivalent of 4.2 billion gallons (19 billion litres) of gasoline.[38]

Reducing fuel consumption through telecommuting

If the work-at-home workforce in the US expanded to include those who could and wanted to telecommute *half of the time*, 114.9 billion miles of vehicle driving could be avoided saving 288 million barrels of oil (of which 36.6% is imported).[39]

ENDNOTES

1 UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013)

2 McKinsey, *Urban mobility at a tipping point* (2018)

3 Ibid.

4 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015) p. 54

5 INRIX, I*NRIX 2015 traffic scorecard sets benchmark for U.S. cities as Federal Government accelerates smart city*, inrix.com (15 March 2016)

6 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015) p. 54; A. Stutzer and B. S. Frey, *Stress that doesn't pay: the commuting paradox* (2004) p. 4

7 Deloitte, *The future of freight*, Deloitte Insights (28 June 2017)

8 P. Rode *et al.*, *Accessibility in cities: transport and urban form*, LSECities (2014) p. 7; UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013) pp. 58, 68

9 Analysts expect continuous growth in e-commerce and increasing demand for rapid delivery. In a circular economy goods and material will also circulate more and locally

10 See for example Deloitte's description of 'smart lockers': Deloitte, *The future of freight*, Deloitte Insights (28 June 2017)

11 ENVAC

12 Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, *Growth Within: a circular economy vision for a competitive Europe* (2015) p. 85

13 DHL, *Press release: DHL expands green urban delivery with City Hub for cargo bicycles* (3 January 2017)

14 UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013) p. 3

15 Deloitte, *The rise of mobility as a service* (2017) p. 114

16 DHL, *Fair and responsible logistics* (2015); UPS/GreenBiz, *The road to sustainable urban logistics* (2017)

17 CrowdToGo, *Video: what is Crowd to Go?;* Kabadiwalla Connect

18 17% of families in Copenhagen own cargo bikes for shopping and transporting children, 25% of which are a direct replacement for cars. City of Copenhagen, *Good, better, best: the city of Copenhagen's bicycle strategy 2011–2025* (2011)

19 Ibid.

20 WHIM

21 RideAustin, *FAQ*; D. Solomon, *Hailing a different ride in Austin*, MIT Technology Review (7 March 2017)

22 DHL, *Press release: DHL expands green urban delivery with City Hub for cargo bicycles* (3 January 2017)

23 Arup, *Cities alive: towards a walking world* (2016) p. 55

24 McKinsey, *Urban commercial transport and the future of mobility* (September 2017)

25 Centre for Cities, *Delivering change: making transport work for cities* (2014) p. 6

26 National Alliance of Public Transportation Advocates, *Infographics*, publictransportation.org

27 Global Workforce Analytics, *Flexjobs: 2017 state of telecommuting in the U.S. employee workforce* (2017) p. 3

28 Arup, *Cities alive: towards a walking world* (2016) p. 57

29 E. Jaffe, *Public transit is worth way more to a city than you might think*, City Lab (14 August 2013); D. G. Chatman and R. B. Noland, *Transit service, physical agglomeration, and productivity in US metropolitan areas*, Transportation Research Board (2013) p. 1

30 Ibid.

31 U.S. Department of Transportation Federal Transit Administration, *Public transportation's role in responding to climate change* (2010)

32 Global Workforce Analytics, *Flexjobs: 2017 state of telecommuting in the U.S. employee workforce* (2017) p. 3

33 UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013) p. 164

34 Mayor of London, *London set to become the world's most walkable city*, www.london.gov.uk (19 July 2018)

35 UN Habitat, *Planning and design for sustainable urban mobility: global report on human settlements* (2013) p. 3

36 American Public Transportation Association, *Facts at a glance*, publictransportation.org

37 OECD, *Urban mobility system upgrade: how shared self-driving cars could change city traffic* (2015) p. 5

38 ICF International, *The broader connection between public transportation, energy conservation and greenhouse gas reduction*, American Public Transportation Association (2008) p. 2

39 K. Lister, *Telecommuting benefits: the bottom line*, TeleworkResearchNetwork.com (2010) p. 23

CIRCULAR
ECONOMY
IN CITIES

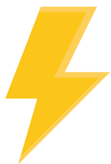
OPERATING AND MAINTAINING URBAN MOBILITY ASSETS FOR EFFECTIVE PERFORMANCE

ELLEN
MACARTHUR
FOUNDATION

ARUP

The operation and maintenance of urban mobility assets can be improved significantly for greater efficiencies and to minimise negative impacts. Vehicles, roads, and street lights can often be operated and managed better. Simple solutions and new technologies can help cities to get more out of their mobility assets (for example through reducing energy use or material use in repairs), while new business models can help overcome financing barriers and create positive incentives. While future operation and maintenance costs need to be planned for and minimised in the design phase, circular economy actions for existing assets will remain important.

CASE FOR CHANGE



Urban transport accounts for **20–50%** of urban final energy consumption (excluding industry); scenarios forecast that it is this consumption that will experience the highest growth[1]

Urban transport is currently the largest single source of global transport-related CO^2 emissions and the largest local source of urban air pollution[2]

An average local UK authority spends around **GBP 20 million** a year on road maintenance[3]

In India, street lighting electricity and maintenance costs can make up **5–10%** of municipal budgets in large cities and up to **20%** in smaller cities[4]

EXAMPLES OF CIRCULAR ECONOMY OPPORTUNITIES

Minimising trip length, duration, and operational energy use with digital solutions

Responsive route planning software can enable users (such as public transport passengers, freight companies or taxis) to optimise routes according to real-time traffic data, as well as the required stops and pick-up needs, in order to reduce transport time and energy consumption.

Mobility assets operated and maintained in new business models

Procuring mobility assets (such as street lights, bikes, vehicles) through new, performance-based, business models that allow the operator to pay for the use of the asset rather than having to procure the product outright, incentivises improvements to the overall operation and maintenance of the asset. Through such a model, the provider is incentivised to provide products and assets that are a combination of durable, adaptable and readily able to be repaired or refurbished, as well as being energy- and resource-efficient. The Philips pay-per-lux model is an example of this approach.[5]

Refurbishing and repairing vehicles to extend material cycles

By refurbishing and repairing vehicles, depreciation and obsolescence of the vehicles and their parts can be slowed down and performance optimised. Prolonging asset life can also reduce the need to produce new mobility assets, which often is more resource- and carbon-intense than maintenance.[6]

New techniques for infrastructure operation and maintenance

When urban mobility infrastructure, such as roads and street lights, need to be upgraded and refurbished, there are a range of measures that can minimise cost while increasing resource- and energy-efficiency. For example, in-situ recycling of old road surfaces is a well-established practice in public road maintenance. Building information modelling (BIM), sensors, and digital twins can also be used to predict maintenance needs and improve overall performance.[7]

RELEVANT CASE EXAMPLES

Nature-inspired route planning to reduce delivery times and costs

Routific has developed a route optimisation software for delivery companies using an algorithm based on how bees discover the shortest route between flowers. Companies using this solution can cut delivery routes by up to 40% according to the company, saving both time and fuel.[8]

Refurbishing public street lights for improved energy performance

In Guadalajara, Mexico, street lighting represented approximately 18% of electricity consumption. To improve the service and operation, and minimise the maintenance costs, Guadalajara entered into a public-private partnership to retrofit LED public lighting into its system through a lease-to-own delivery model with private company financing repaid over 10 years. Expected energy savings will be around 50–55%, equating to a cost saving of USD 500,000 per month.[9]

Refurbishing ambulances to extend lifetime

DLL – a global provider of asset-based financial solutions – introduced the concept of modularity in the refurbishment stage of ambulances through an innovative remounting process. The remounting process involves refurbishing the box body of a used vehicle to an ‘as-new’ standard. The box is a module which is then fitted to a brand new chassis, providing reliability and efficiency as well as extending its useful life by 5–7 years and reducing investment costs for the end customer by more than 20%.[10]

100% road material recycling in Hamburg

When one of the main roads in Hamburg needed to be refurbished and resurfaced, the city decided to include a 100% recycling and reuse requirement in the procurement tender, ensuring that all the old road material was reused in the same road. The road was laid in 36 hours and provided a 30% cost saving compared to conventional road resurfacing, and it still had the same properties and durability as new asphalt. Other benefits included reduced energy consumption and CO^2 emissions, as well as minimised noise and traffic disruption.[11]

EXAMPLES OF WHAT URBAN POLICYMAKERS CAN DO

Taking a circular economy approach to **asset management** of mobility infrastructure and vehicles can improve operations and reduce maintenance costs (for example with predictive maintenance technology or in-situ pavement recycling). When replacing and renovating mobility infrastructure, city governments can integrate circular economy criteria in **public procurement** tenders to incentivise circular economy solutions.

To explore further see **Policy Levers**

EXAMPLES OF LINKS TO OTHER SYSTEMS AND PHASES

Mobility: Designing Operation and maintenance costs can be planned for or minimised in the design phase, for example increasing durability or by ensuring easy disassembly.

EXAMPLES OF BENEFITS

ECONOMIC PRODUCTIVITY

Saving travelling time

Anonymised transport data released to the public by Transport for London (TfL), enables third-party organisations to create real-time journey planners. This helps public transport users save time to the economic value of between GBP 15 million and GBP 58 million per year. It also unlocks new revenue and savings opportunities for TfL, and a GBP 20 million increase from bus usage, as customers are more aware of service opportunities.[12]

Reducing freight kilometres

Dynamic delivery route-planning software can cut delivery routes by up to 40%.[13]

Reducing street light operation and maintenance costs

In the US alone, replacing outdoor lighting with LED lighting can save USD 6 billion annually through reduced energy use, as well as reduced operations and maintenance costs because LED luminaires last at least four times longer than traditional bulbs.[14]

Reducing traffic disruption

In-situ recycling for road maintenance can reduce the duration of traffic disruption by around 50%.[15]

HEALTH AND ENVIRONMENT

Reducing light energy CO^2 emissions

Replacing outdoor lighting in the US with LED lighting can reduce carbon emissions by the equivalent of taking 8.5 million cars off the roads for a year.[16]

Increasing worker safety

Use of some in-situ recycling processes reduces workers' exposure to Hand Arm Vibration Syndrome, which is a health concern that arises from regular paving processes.[17]

RESOURCE USE

Minimising embodied energy

Across individual case studies, refurbishment of vehicle parts, industrial digital printers, and heavy-duty truck and off-roading (HDOR) equipment parts saved 57–87% of process energy and 80–99% of embodied material energy; repair saved 93–99% embodied material energy.[18]

Enabling easier repairs

Additive manufacturing or 3D printing of machine components can enable faster repairs since damaged parts can be 're-printed', supporting longer product lifetimes.[19]

Saving road material costs

The use of recycled materials for highway maintenance is often cost neutral, and in many cases can deliver good financial returns. In the UK, the Newport Southern Distributor Road Scheme saved GBP 1 million by using around 450,000 tonnes of recycled and secondary aggregates instead of purchasing primary materials. In-situ recycling techniques employed for Essex County Council in the UK gave direct cost savings of nearly GBP 200,000.[20]

ENDNOTES

1 B. Lefèvre, *Urban transport energy consumption: determinants and strategies for its reduction. An analysis of the literature*, Surveys and Perspectives Integrating Environment and Society (2009)

2 P. Rode *et al.*, *Accessibility in cities: transport and urban form*, LSECities (2014) p. 3

3 Excluding London. House of Commons, *Local road maintenance, repairs and street works in England* (2016)

4 World Bank, *LED street lighting: unburdening our cities*, blogs.worldbank.org (7 August 2017)

5 Ellen MacArthur Foundation, *Selling light as-a-service*, Case Studies

6 For example, almost half of an electric vehicle's carbon footprint is in production, which in absolute terms is greater than a traditional vehicle. Keeping the vehicle in efficient use is therefore important to offset the carbon production costs. LowCVP, *Lifecycle emissions from cars – Annex 1: LowCVP press release* (2015)

7 Infrastructure and Projects Authority, *transforming infrastructure performance* (2017) p. 34

8 Routific, *Case Studies*

9 World Bank, *Proven delivery models for LED public lighting lease-to-own delivery model in Guadalajara, Mexico* (2016)

10 Ellen MacArthur Foundation, *DLL Group: how refurbishment can work, even when safety and performance matter the most*, Case Studies; DLL, *Emergency services vehicles*

11 European Commission, *GPP in practise: recycled asphalt used for road resurfacing*

12 National Infrastructure Commission, *Data for the public good* (2017) p. 42

13 Routific, *Case Studies*

14 World Bank, *LED street lighting: unburdening our cities*, blogs.worldbank.org (7 August 2017)

15 WRAP, *Recycled roads* (2005) p. 6

16 World Bank, *LED street lighting: unburdening our cities,* blogs.worldbank.org (7 August 2017)

17 WRAP, *Recycled roads* (2005) p. 6

18 International Resource Panel/the UN Environment, *Re-defining value: the manufacturing revolution – summary for policymakers* (2018) p. 21

19 Siemens, *Additive manufacturing*

20 WRAP, *Recycled roads* (2005) p. 5