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HORIZONS

Urban Mining

What is urban mining and what is the current state of play?

What's already possible now and what more does the future hold?

International spotlight: Amsterdam and the doughnut model

From rhetoric to implementation: the stakeholder cycle

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acatech's HORIZONS publication series explores significant fields of technology that are looming large on the horizon, but whose impact remains uncertain, and provides a clear, well-founded outline of the issues at stake. This process takes account of the current state of international research, development and application as well as the value creation potential of the technologies. acatech HORIZONS also addresses ethical, political and social issues as well as conceivable developments and options for the future. acatech's aim with the HORIZONS series is to stimulate discussion about new technologies, to identify the scope for political action and to set out policy options – and so make a contribution to forward-looking innovation policy.

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Contents

Twelve key messages

1. Germany and Europe obtain a large proportion of their raw materials from other countries around the globe. Some of these raw materials are critical and of vital significance for key technologies in the economy. Unfortunately, in certain areas they are extracted under unacceptable environmental and working conditions.

2. Urban mining can help not only to reduce Europe's dependency on raw materials imports from third countries but also its environmental footprint.

3. Instead of mining ever more primary raw materials, urban mining focuses on the secondary raw materials which accumulate in cities and settlements over the decades. These may be precious metals from electronic parts, building materials or even plastics.

4. Urban mining also involves data mining because data is required to locate, reprocess and recycle the individual material components.

5. Key to effective urban mining is to always consider recycling aspects whenever designing a product. Thinking in advance is an approach which ensures the effective and precise separation of the individual raw materials used.

6. In particular, this applies to (highly) toxic substances that can be found in multiple materials posing a hazard to the environment and health. Often these threats become apparent when the materials have already been used, for instance in the case of building contaminants. Consequently, the safety of such materials needs to be investigated in advance in order to avoid having to remedy the damage years later.

7. Researchers are working on various recycling technologies that are waiting in the wings to enter into application. Which of these will catch on remains an open question.

8. Practical implementation is paramount: experience is vital to demonstrate that urban mining can also be economically successful. There is a need to try out many different approaches and to keep on going even in the absence of an immediate 'quick win'.

9. If urban mining is to be a success across the board, there is a need for new business models which also make economic sense. This is precisely the challenge, because up to now primary raw materials have usually been cheaper than recycled ones.

10. Policy makers can provide an important incentive by promoting the use of recycled materials. Such approaches are already being tested in the construction sector in Europe.

11. Urban mining demands coordinated thinking and action by all parties concerned, including architects, designers, development and construction engineers, product manufacturers, cities, local authorities, policy makers, researchers and, last but not least, consumers, who can work together to drive the issue forward.

12. One factor which is of particular interest to the business community is that urban mining can help German and European companies become more competitive globally by increasingly focusing on sustainable approaches.

1 Introduction: what is urban mining and what is the current state of play?

There are probably only a few people who have any idea at all what urban mining might be. What does it involve? Why is it important and who does it affect? Chapter 1 provides an overview and reveals the hidden treasures in our cities.

"Now is the time to achieve a change in thinking."*

The processing of raw materials is estimated to be responsible for 30 per cent[1] of global greenhouse gas emissions.[a] Moreover, Germany and Europe are relatively resource-poor regions, which is why raw materials are mostly mined in other countries of the world and imported by Europe. This results in sometimes serious environmental harm and human rights abuse.[b] Although Germany does still have a domestic mining industry for building materials, minerals and brown coal, it is entirely dependent on imports for metals and ores (apart from resources from recycling).[2] As a result, it makes little sense to simply throw away objects and thus the valuable, costly raw materials they contain.

Urban mining concerns each and every one of us. Everything that humans have ever made and used is part of a huge storehouse of raw materials: entire cities, settlements, conurbations or production sites. We are thus facing a paradigm shift. Bridges, old buildings, factories, worn-out (durable) consumer goods – basically anything that humans have produced and later discarded or regarded as useless is no longer waste but valuable (buried) treasure lying dormant on our doorstep, waiting to be dug back up.

Urban mining is about systematically finding this buried treasure and reprocessing it to a high quality so it can be put to renewed use. Implementation is still in its infancy for many raw material groups: overall, only some 16 per cent[1] of raw materials used in the German economy are secondary raw materials.[c] Technologically, much is already possible and what's needed now is to move out of the laboratory into the real world and test new business models (see Chapter 2). Pilot projects in Europe are in the process of demonstrating that implementation is feasible and can be successful (see Chapter 3). One thing is already certain, however: it can only work if all stakeholders – policy makers, business, science and each and every individual – pull together (see Chapter 4).

This chapter's illustration offers an overview of the most important raw material groups present in the "anthropogenic", i.e. man-made, stock.

Urban mining and the Circular Economy: same same but different

Did you know that urban mining is embedded in the concept of the Circular Economy? However, there is a difference: while the Circular Economy deals with durable and non-durable consumer goods such as packaging, urban mining deals with the question of how long-lived[d] goods can be reused, repaired, reprocessed and recycled in order to put them repeatedly back into circulation. This means that urban mining goes far beyond traditional waste and recycling management.

If you want to learn more about the Circular Economy, take a look at the Circular Economy Initiative Deutschland co-founded by acatech. Its report "Circular Business Models: Overcoming Barriers, Unleashing Potentials"[3] sets out a roadmap for implementing circular business models.

Urban mining: conserving resources in the Anthropocene

"If the anthropogenic, i.e. man-made, stockpile keeps on growing, why not make greater use of it as a source of raw materials? Why dig deeper and deeper for natu-ral resources or keep on increasing imports from distant countries when material wealth is literally on our door-step? Urban mining views our immediate habitat as a source of raw materials. In the broadest sense, it is about extracting reusable materials from any man-made source, i.e. buildings, infrastructure, (durable) consumer and capital goods and more. So urban mining extends the maxim 'waste is a resource' known from conventional recycling management."[2]

"Urban mining on the one hand involves reclaiming 'hidden resources' within our cities. On the other hand, we really have to think today about how to make products so that we can in future find them more efficiently, recycle them more cleanly and put them to renewed use."

a Recycling also requires energy, yet it causes significantly lower greenhouse gas emissions than the extraction of primary raw materials which has an environmental impact as well.[1] Primary and secondary raw materials could in future be extracted and processed in a greenhouse gas-neutral way if energy requirements can be met from renewables.

b It should be noted that progress is also being made in the extractive sector to reduce or entirely avoid the harm caused by mining; the main obstacles are usually to be found at regional or local level. Irrespective of urban mining, efforts should be made to ensure that today's raw material extraction is without exception carried out to the highest safety and environmental standards. At the same time, it is already necessary to consider how alternative employment opportunities can be created for miners in the producing countries in the future, especially since many jobs currently depend on the extraction of raw materials. It is to be expected that the development of new economic sectors, for example in the field of renewable energies, will also create new jobs worldwide.

c Of course, the amount of secondary raw materials that can be extracted also depends on the quantities and useful life of the primary raw materials that the urban stock can provide, measured against demand.

d The German Environment Agency (Umweltbundesamt) defines durable goods as "all those goods that remain in use for on average one year or more and form stockpiles of a significant size."[2] It is, however, sometimes difficult to draw a clear distinction between durable and non-durable goods.

* Some selected key ideas expressed by interviewees are included in the text as anonymised quotes.

The anthropogenic stock:
in search of hidden treasure

Approaching 80 per cent of Germans live in cities and conurbations – and the trend is rising. Building new houses and amassing ever more (durable) consumer goods results in an accumulation of valuable raw materials which often remain unused, so giving rise to the anthropogenic stock, a gigantic stockpile of raw materials created by humans.

Mineral materials

For each person in Germany, 317 tonnes of mineral materials, including materials such as concrete, sand and stone, have been used in construction. In total, the estimated value of these materials is around 350 billion euro.

Residential and non-residential buildings such as industrial buildings consist of around 90 per cent mineral materials. The most common building material is concrete.

In civil engineering, mainly mineral building materials are deployed, for example in infrastructure systems such as sewerage and wastewater systems.

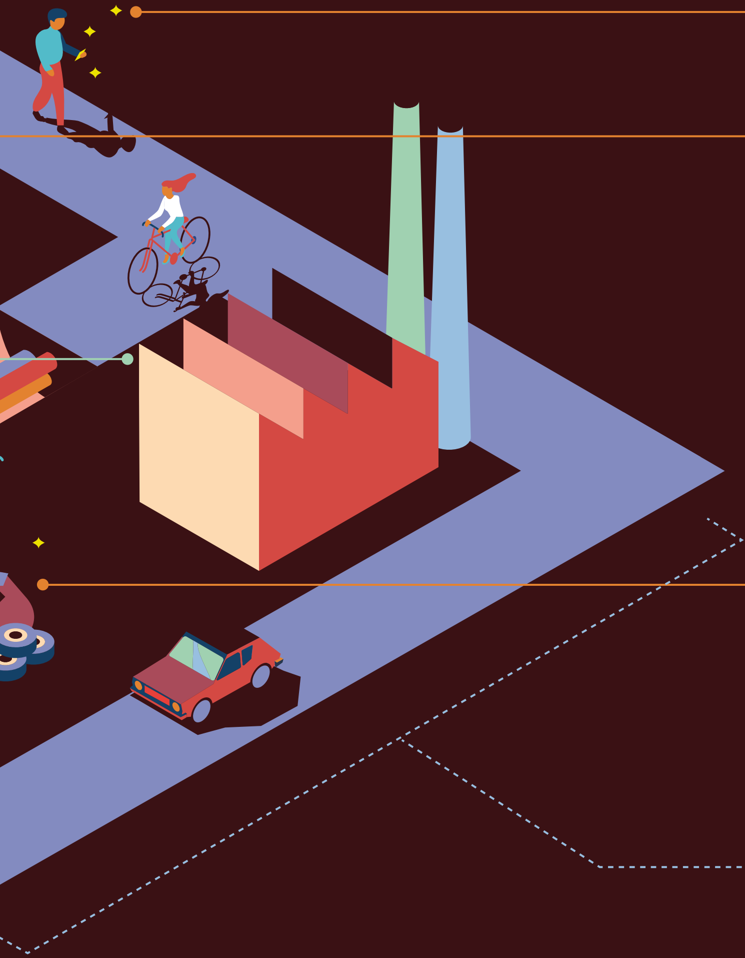
Plastics and wood

There are more than 3 tonnes of plastics and 4 tonnes of wood per person in Germany. The overall value is estimated at 150 billion euro.

Plastics are mainly found in buildings, but also in civil engineering, vehicles and electrical appliances.

An average old building contains around 30 tonnes of plastics, sealing materials and wood.

Source: own presentation after German Environment Agency 2017[2] and Zech 2018[4]



Metals

For each person in Germany, 14 tonnes of metals, primarily steel, have been processed, the majority used in construction in the form of reinforced concrete. Much of the metal is to be found in heating systems, pipework or consumer products. Of all the types of material, the metals used in construction are the most valuable, their total value being estimated at 650 billion euro.

A smartphone contains as much gold as 16 kilograms of the gold rock or gold ore from which the raw material gold is extracted.

One metre of copper wire from the IT and communications sector contains as much metal as 2.5 tonnes of the ore from which the raw material copper is extracted.

Several million tonnes of copper, iron and aluminium scrap with an estimated value of 14 billion euro have accumulated in landfill sites over the years.

What are we not looking at?

Considerable quantities of often overlooked materials also flow into the anthropogenic stock, including:

- long-lasting goods such as paints, coating materials, lubricants and adhesives or plastics additives and
- short-lived goods such as tyre particles, cleaning agents and detergents, cosmetics and care products.

The vast majority ends up in household waste or domestic wastewater or is released directly into the environment.

2

What's already possible now and what more does the future hold?

There are valuable raw materials to be found in smartphones, homes, batteries, cars, textiles and many other things. But how can these materials be recovered, what's already possible now and what more does the future hold? Which technologies are scientists already researching in the laboratory and what new business models might potentially emerge? Why are these not yet in use across the board and what obstacles still stand in their way?

2.1 Metals: turning waste into gold

"Critical metals are used in large quantities and mostly come from abroad."

Each year, Germany produces 1.6 million tonnes of electrical waste[5] and in the process discards valuable metals which were mined in many countries of the world with considerable inputs of resources and energy. Even gold is used in laptops and smartphones because it is particularly suitable for transmitting data. The first illustration in this chapter shows which raw materials are to be found in a smartphone. The second illustration indicates how scientists can use new technologies, for instance biotechnological processes, to recover valuable metals from smartphones. This is already possible in the laboratory and in future this technology will not only ensure greater sustainability, but also open up new areas of business for industry.

So why isn't this already happening?

The biotechnological process[6] shown in the illustration is one of several recycling processes that various institutions, companies and countries are subjecting to initial laboratory testing. Whether any of these technologies will succeed on an industrial scale remains to be seen. While a biotechnological approach is more environmentally friendly than chemical processes, the initial investment involved in introducing a new technology is always a stumbling block for companies. It may well take years to extract sufficiently large amounts of gold from very large numbers of smartphones for the investment to pay off. One possible approach is a deposit system which creates incentives to return the "hibernating" mobile phones lying around unused. According to surveys conducted in 2018, there were 124 million such mobile phones in Germany alone,[7] despite the country having a deposit system of this kind.[8] This is however not yet operational on a large scale.

"The production phase may be associated with greater environmental impact than the use phase. So we definitely need to extend use. A laptop would have to be used for decades to make the energy inputs during production worthwhile."

What's inside a smartphone?

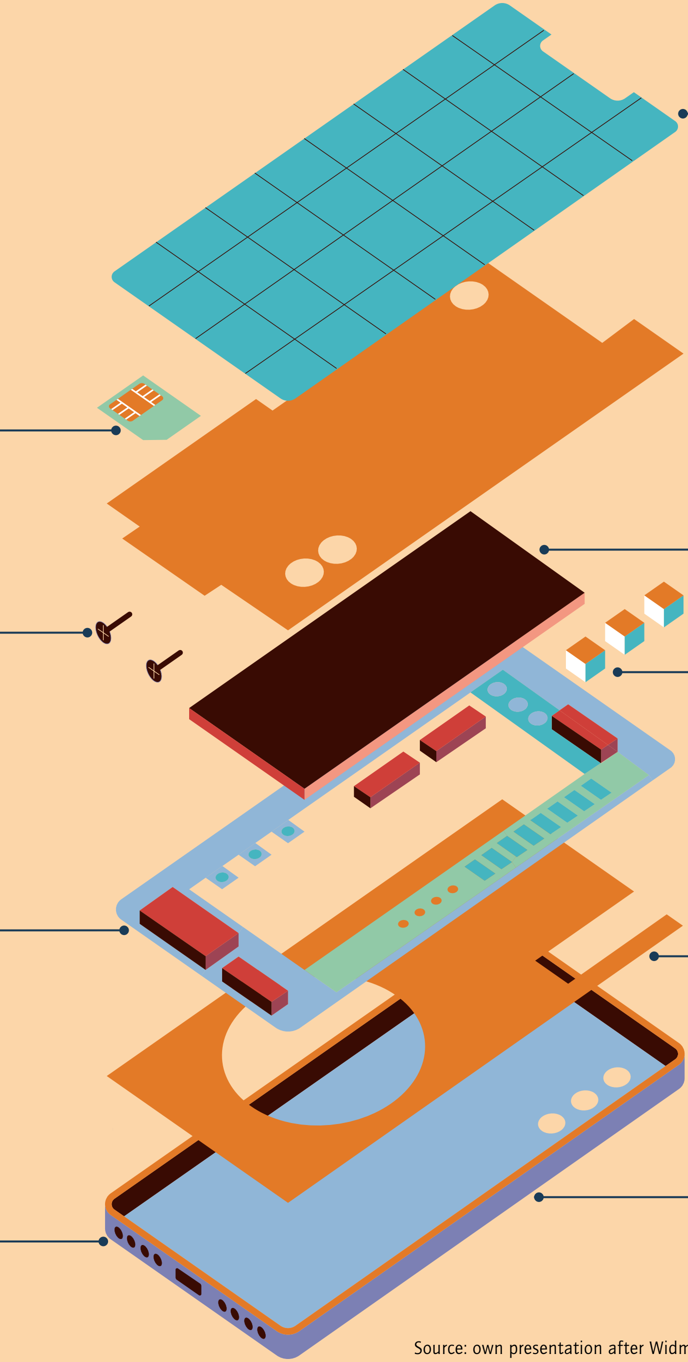
Hardly anyone can imagine life without a smartphone. But only very few know that a single mobile telephone consists of 60 different materials from round 270 suppliers! This makes it difficult to trace global supply chains and monitor working and environmental conditions right along the line.

SIM-Card
- **Gold** is particularly conductive and is therefore very suitable for data transmission.

Screws
- **Iron** is mined in China, Australia, Brazil, India and Russia.

Printed circuit board
- **Copper** conducts electricity and is extracted from mines in Chile, Peru and China, often resulting in contaminated soil and water.
- **Silver**
- **Tin** is used for soldering components and **tantalum** for storing energy. Both of these conflict minerals are key metals in the electronics industry. Tantalum is mined in war and crisis zones, including Congo, Rwanda and Nigeria.
- **Palladium**

Loudspeaker
- **Neodymium** is one of the rare earth metals which are virtually never recycled nowadays.



Display
- **Aluminium**
- **Gallium**
- **Indium**
- **Tin** comes from China, Indonesia and Myanmar.
- **Dysprosium** and **yttrium** are rare earth metals.

Battery
- **Lithium**
- **Cobalt** is irreplaceable for lithium-ion batteries and comes from mines in the Congo, where children sometimes work under the most difficult conditions. It therefore counts as a “conflict metal”.
- **Gold** is also a conflict metal and is obtained from China, Australia, Russia, the USA and Canada among other places.

Camera
- **Gallium** can only be obtained with a high energy input. China is the most important supplier.

Shielding
- **Aluminium** is extracted in Australia, China, Guinea and Brazil.

Casing
- **Plastics**
- **Nickel**
- **Glass** and **ceramics**
- **Aluminium**

Source: own presentation after Widmer 2019[9]

A look inside an old smartphone: turning waste into gold

Smartphones, chargers and other electronic goods contain valuable metals such as gold, silver, platinum and palladium, which are more in demand than ever as they are needed for high-tech products. How-ever, a large proportion of electronics ends up in residual waste and is incinerated in waste disposal facilities.

In the waste incinerator ash, the valuable metals appear in the form of particles, which are so tiny that they can only be sorted with great difficulty. As a result, up to 20 kilograms of gold are lost per year from a single waste disposal facility.

The incinerated waste is used in road building, so Germany is literally paving its streets with three tonnes of gold every year.

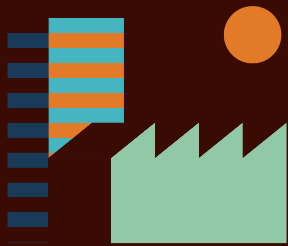
The fictional city of Silvertown shows what is possible now and in the future.

A **scientist** working at the university in Silvertown has invented a biotechnological process to extract tiny particles of valuable metals from incinerated waste.

Source: own presentation

Very special microorganisms come into play here: bacteria that live in old mine workings dissolve metals in a natural, environmentally friendly way. They now turn waste into pure gold.

A global **smartphone manufacturer** recognises the opportunity and, aiming to transfer the technology from the lab to the real world, firstly builds a pilot plant in Silvertown.



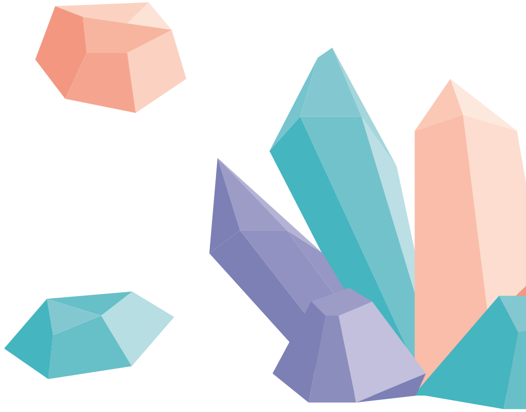
By offering incentives, the manufacturer convinces its **customers** to recycle their hibernating smartphones. As a result, it recovers valuable raw materials and is less dependent on raw material imports.

The manufacturer also wins new customers by producing more sustainably. The Silvertown pilot plant runs so well that the smartphone manufacturer transfers the new business model to its global manufacturing operations.

The **recycling company** also comes on-board and prospects for gold and valuable raw materials in old electrical goods.

Even "worthless" metals such as iron can be recycled using this approach. Even if this is not initially profitable for business, **policy makers** provide incentives to keep as many materials as possible in the loop and promote more sustainable electronic products.

Thanks to the new technology, **consumers** can choose to buy more sustainable products. Once the smartphone has reached the end of its useful life, it can be recycled again.



2.2 Mineral materials: a new house made from waste

"Resources, including sand, are finite and highly sought-after. Apparently, sand 'pirates' have already caused the disappearance of two islands in Indonesia."

Each year, 40 billion tonnes of sand[10] are used in construction worldwide. Sand can be used to manufacture soaps, glass, cleaning agents and even computers, but most importantly concrete for construction. Concrete made from desert sand is not suitable, however, because it does not have the necessary strength. This leads to the ludicrous situation of, for example, the desert state of Dubai importing sand from Australia. As a result, the world might suffer shortages of sand in as little as ten years. Even if this situation is only indirectly related to Germany's sand supply, this valuable raw material should obviously be recycled. After all, sand mining and the long transport distances involved have a substantial environmental impact. Currently, a large proportion of used concrete in Germany ends up in road building,[e] but scientists have discovered a new solution. The next illustration[f] shows an example of what is already possible in the laboratory today and what will be possible in practice in future if all stakeholders play their part.

e It would make the most sense to keep concrete in a closed loop. However, before having to use primary material for road building, it obviously makes more sense to make use of used concrete. What must be avoided at all costs is landfilling used concrete. In addition, the ratio of available recycled material to demand must be considered. According to current data, we will not be able to do without primary mineral raw materials.[11]

f The building material concrete was chosen as an example for the illustration, not least because it is the most commonly occurring mineral building material. However, other mineral substances, for instance gypsum and brick, also have the potential to be recovered and recycled.

So why isn't this already happening?

While the recycling process shown in the illustration already works in German laboratories, it has yet to find its way into industry. Recycled concrete is already being used in individual pilot projects throughout Germany but the real-world situation in the construction industry is different. This is partly due to the costs: primary raw materials are (still) so cheap that recycling is not yet financially viable. Secondly, most German cities and local authorities put deconstruction and new building construction out to tender according to price criteria and not according to sustainability, which means that recycled concrete hardly stands a chance. Experts have there-fore suggested that tender criteria should be modified in such a way that recycled material does have a chance. Some have also considered the possibility of introducing a raw materials tax on sand and gravel. This would make the production of primary concrete more expensive and recycling more financially rewarding. A raw materials tax is incidentally already being tested in the Netherlands (see illustration in Chapter 3).

Switzerland is one step ahead when it comes to concrete recycling. A pilot plant in a Swiss concrete factory is testing a process that uses crushed concrete and carbon dioxide to produce rock which can be used as the basis for primary concrete.[12] The City of Zurich has put incentives in place for this purpose and, since 2005, in line with the city's requirements, all public buildings in Zurich have been built with recycled concrete.[13] As a result, numerous buildings, including housing and schools, have been built using recycled concrete from the region. As an additional boost for the environment, this also avoids long transport routes.

"Recycling technologies will coexist. It would be negligent to overlook a technology. No one knows which one will win the race."

Green building certification for more sustainability

Did you know that you can have a building certified? The aim is to make the sustainability of buildings measurable, comparable and assessable. In this way, certification is intended to create incentives to pay attention to economic efficiency, greater sustainability and environmental compatibility throughout the entire life cycle of a building – from planning and construction through operation and refurbishment to deconstruction. There are also such initiatives in Germany,[16] [17] but so far there are no generally applicable evaluation criteria.

Safe-by-Design: better safe than sorry

Virtually all materials and products in today's society contain chemical additives, some of which are toxic. These are incorporated into building materials, plastics and electronics to perform specific functions. However, these substances also harbour risks; for instance, pollutants and impurities escape from the crushed sand when a building is deconstructed. This is why crushed sand is also referred to as the „kidney" of the circular economy. Another example is toxic fire retardants used in polystyrene insulation. "Substances of Very High Concern" (SVHC),[14] which can have serious consequences for human health and the environment, are particularly dangerous. While these are documented by law at EU level, their presence is still permitted in certain products because no better alternatives are yet available.

When recycling, it is essential for these and other pollutants to be separated and disposed of safely. This is a particular obstacle to recycling without harm and consequently to the recyclability of buildings and products, especially as waste is seldom sorted by type. In most cases, it is a mixture of materials, as in the case of building rubble. This is why Germany already has separate collection requirements, for example for construction waste in the Commercial Waste Ordinance. Crushed concrete, brick and ceramics are, where proportionate, to be collected separately. However, information about material composition is often missing (see Chapter 2.6). Even if one hundred per cent freedom from pollutants is the desired goal, it has not yet been achieved. This means that incineration of some waste remains indispensable so that the discharged pollutants can be safely destroyed and the residues safely landfilled.

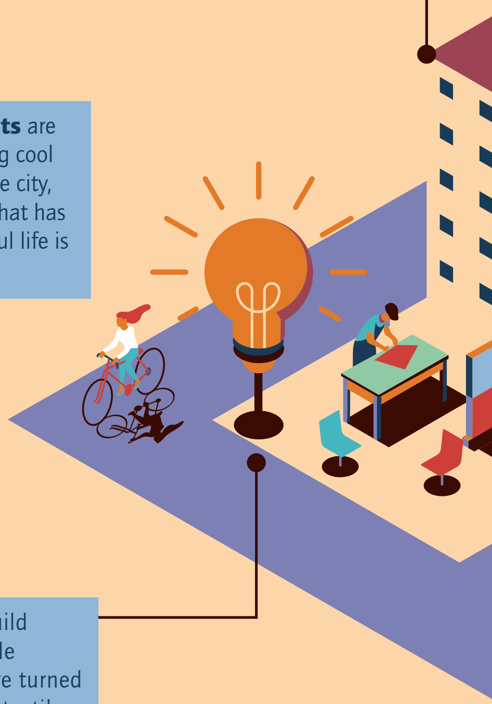
Looking to the future, scientists are researching a new concept: safe-by-design, which aims to consider the issue of safety from the outset in the design and development of new products and materials, before any harm occurs. Under the motto "better safe than sorry", the search is on for non-toxic alternatives to harmful substances.[15]

Recycled concrete: new life from waste

Over half of Germany's waste is construction and demolition waste. The majority of used concrete ends up in road building. New scientific findings could mean that concrete can be recycled. There are even pilot projects to investigate how to build entire houses from recycled materials. The fictional city of Silvertown shows what is possible now and in the future.

The old building needs to come down. The **city** of Silvertown, which is responsible for clearance, also known as deconstruction, thinks innovatively, looking at speed, price and sustainability when issuing invitations to tender. This means that recycled materials also have a chance.

Homeowners and tenants are thrilled: not only is recycling cool but, being subsidised by the city, also affordable. Anything that has reached the end of its useful life is recycled again.



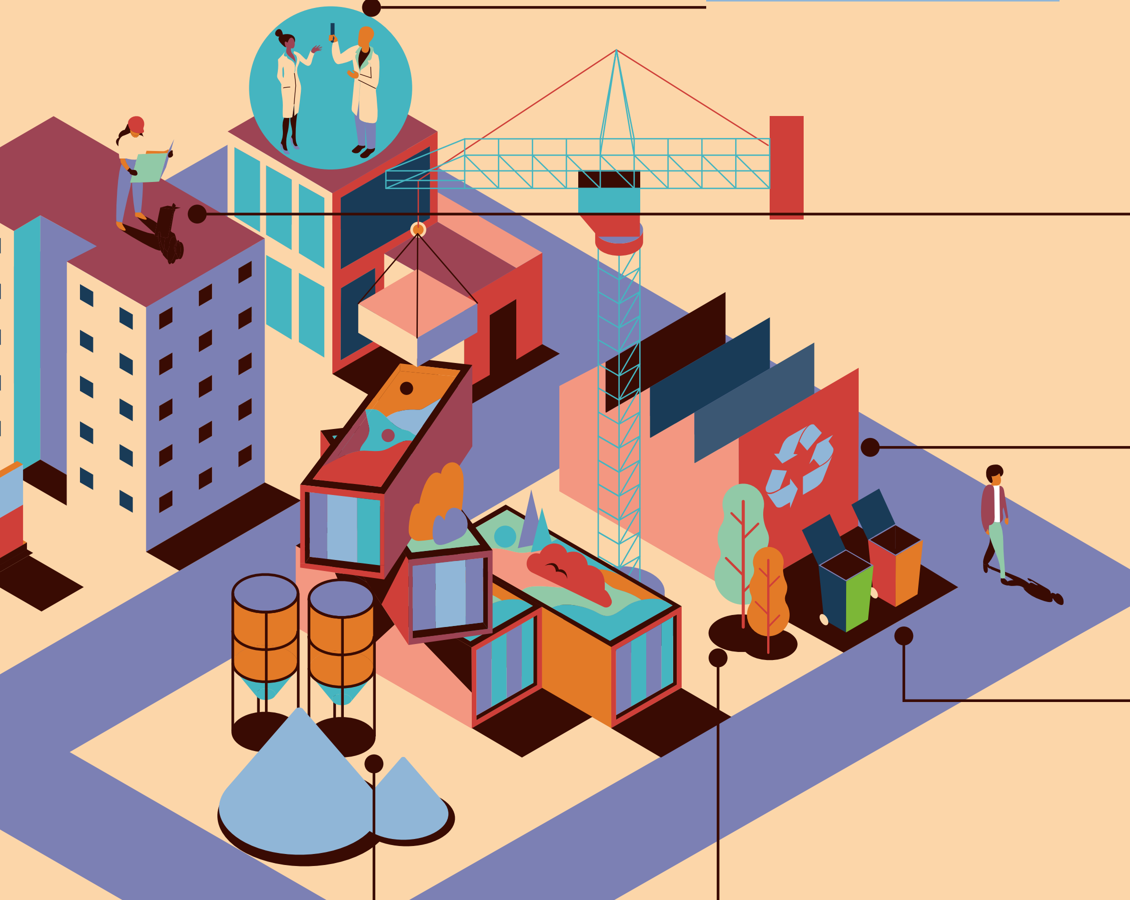
New **start-ups** aim to build furniture from old valuable materials: used clothes are turned into a highly compressed textile sheet material which can be used as a stool or room divider while food packaging and DVD cases become chic designer chairs. Chemical adhesives are replaced with natural adhesives made from mycelium, i.e. the root-like structures of fungi.

Source: own presentation after BMBF 2020[18] and ambista 2020[19]

Concrete is almost indestructible: once cured, it can no longer be broken back down and consequently, after deconstruction, ends up in road building. As a result, it is not recycled to a high standard and is lost to the economy. Since sand is in short supply and highly sought-after, this is a waste of resources!

After many decades, **researchers** finally have a solution: extremely short underwater flashes of light blast the concrete apart, breaking it down into its original components of sand, gravel, cement and water. The process is powered by renewable energy.

The technology has matured to such an extent that recycled concrete can achieve the same strength as original concrete – not just in the laboratory. For the first time, scalable projects for **industry** are conceivable.



Silvertown recognises the potential and becomes a pioneer, firstly appointing a **demolition manager** who seeks out reusable materials in old buildings. A new job created by the city!

Ideally, all valuable materials are reused on deconstruction and taken to a **recycling platform**, where old materials, including concrete, can be dropped off, exchanged and recycled.

Since it saves them landfill costs, **recycling companies** think the platform is a great idea.

Silvertown then commissions a **building company** to construct a residential building from recycled concrete. A hip **team of architects** comes up with a new living concept: flexible building modules that can be transformed from office to apartment to a space for cultural activities.

The municipal gravel plant has also come up with a new business model: concrete leasing, which involves used concrete always being returned to the **gravel plant** where it is permanently recycled and kept in the loop.

2.3 Plastics: bio-recycling with bacteria

"In the plastics sector, producing virgin material is cheaper than reprocessing used material. That's why recycling technology has stood still since the 1980s."

The past two decades have seen per capita plastics consumption double in German households. Although Germany is often perceived as the recycling world champion, there is still room for improvement when it comes to plastics: although some German plastics waste[g] is recycled in plants in Germany or abroad, more than half is used for energy recovery, i.e. is incinerated[20] (see box "Not all recycling is the same").

The challenges are huge. Firstly, virgin plastics are cheaper than recycled plastics. Moreover, over the course of the coronavirus pandemic, there has been a fall in the price of oil, i.e. the raw material for plastics, as a result of which plastics production costs have fallen still further. Secondly, every plastics manufacturer has a different plastics composition which it offers for sale and which distinguishes it from the competition. For instance, polypropylene alone, which is considered a standard plastic, has over 1,500 variants[21] and that's without taking account of additives. This wide variety of plastics is a problem for recycling companies, as only single-grade plastics can be effectively recycled. The second illustration in this chapter shows how innovative ideas can emerge from difficult situations.

"It is only once recycling creates high-quality products that these products become economically worthwhile and are of interest to businesses and consumers."

Not all recycling is the same

The simplest way to recycle plastic is to burn it. That is undoubtedly better than landfilling it, let alone dumping it into rivers and oceans. Incineration also produces energy, for example for generating electric power or heat. However, the raw material does not remain in the loop but instead "disappears" after incineration, releasing large quantities of greenhouse gases in the process. This is why experts advocate high-quality recycling of plastics, which would mean, for example, turning an old polyester garment into a new one or using old polyvinyl chloride (PVC) window frames for new windows. In this way, valuable materials continue to flow back into the same application and remain in the loop. This can moreover be achieved by breaking plastics back down into their original building blocks and so continuously producing high-quality, virgin plastics (see illustration). If we are to get closer to this goal, recycling should not be measured solely in terms of recycling volumes and rates, as is currently the case. Instead, quality should also enter into the equation, i.e. how high-grade the recycling is.[h] Consumers would also benefit from an eco-label reflecting the quality of a recycled product.[1]

g These include both long-lived and short-lived plastics waste. Strictly speaking, short-lived plastics such as packaging or bottles are not the concern of urban mining. Due to the major environmental impact of plastics waste in general, this chapter makes no clear distinction between long-lived and short-lived products in order to clarify quite how explosive this issue is.

h "Substitution rates", i.e. the proportion of secondary material in the overall material are also of use here. Of course, the quality must be right here too.

CO_2 and climate protection – two different kettles of fish?

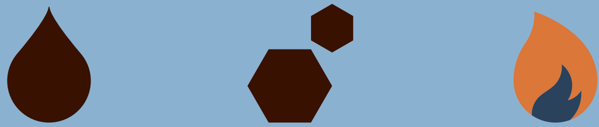
Did you know that CO_2 can also be used as a raw material? Researchers are currently working on capturing greenhouse gases in the future, recycling them or storing them deep underground and possibly subsequently putting them to use as a raw material. Such CCUS (Carbon Capture, Usage and Storage) technologies could help to ensure German industry achieves its emission reduction targets by 2045. If you would like to find out more, take a look at acatech's POSITION PAPER "CCU and CCS – Building Blocks for Climate Protection in Industry".[23]

So why isn't this already happening?

The bio-recycling illustration relates to a new biotechnological approach that is still in its infancy and is being researched by start-ups and established companies. The process does, however, require the plastics waste to consist of pure polyethylene terephthalate (PET) and not to be mixed with other types of plastic. However, the reality is that plastics waste is too heterogeneous. This process therefore cannot break the waste down completely, so some is still incinerated or landfilled. In addition, there have not previously been economic incentives for plastics recycling which reward recycling and penalise the production of new plastics, or at least do not promote it through subsidies. The new EU "plastics tax" on non-recycled plastics,[22] which is set to come into force from 2021, is obviously intended to provide such an incentive.

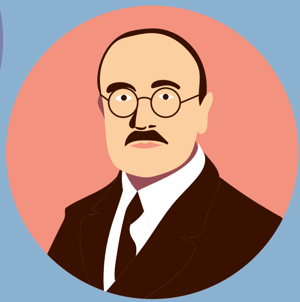
"Penalising waste boosts innovation in more sustainable products."

Plastics: facts and figures



Plastics are predominantly made from fossil fuels such as coal, oil and gas.

Alexander Parkes



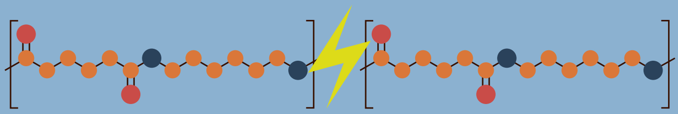
Leo Hendrik Baekeland

Who invented plastic?

The first plastic, made from plant cellulose, was known as Parkesine and was developed by the Englishman **Alexander Parkes** in 1856. The first truly completely synthetic plastic – Bakelite – was produced by the Belgian-American chemist **Leo Hendrik Baekeland** in 1907.

*Shares of different types of plastic and their recycling code symbols in Germany 2017

Source: own presentation after Heinrich Böll Foundation 2019[24] and Fraunhofer UMSICHT 2020[25]



Plastics are **polymers**, i.e. molecules which consist of many individual building blocks, which are also called monomers. These monomers are linked together in a chemical reaction known as polymerisation. Polymers also occur in nature and in our bodies. Our genetic information, DNA, for example, is also a polymer, as is cellulose, which makes up about 50 per cent of wood in trees.

Not all plastics are the same and they are classified among other things by their properties:

- **Thermoplastics:** soften when heated and harden again when the temperature is reduced, recyclable (e.g. Lego bricks)
- **Thermosets:** once cured, they retain their shape and cannot be remelted, not recyclable, durable (e.g. car bodies, electronic housings)
- **Elastomers:** resiliently deformable, not readily recycled (e.g. car tyres, shoe soles)

Plastics – the essentials:

Polymer + additives = plastic

In addition to a polymer, most plastics contain additional components, or additives, which give them certain properties. Examples of frequently used additives are plasticisers, fillers, stabilizers, flame retardants and colorants. While many of these chemical additives do make plastics flexible or durable, they can also be harmful to the environment and health.

The term plastic is derived from the Greek plastikós (πλαστικός) meaning 'shapeable'.

The most important plastics at a glance*:

01 PET

Polyethylene terephthalate (PET) (6%): single-use food packaging and beverage bottles, also used in sportswear; problem during recycling: absorbs odours and flavours, use of hazardous chemicals for purification

02 PE-HD

High density polyethylene (13%): cleaning agent containers, pipes for gas and drinking water, shampoo bottles; relatively safe and well suited to recycling

03 PVC

Polyvinyl chloride (13%): shower curtains, window frames, floor coverings, electrical cables, imitation leather; contains harmful chemicals, has to be specially recycled

04 PE-LD

Low density polyethylene (15%): plastic bags, cling film, rubbish sacks, tubes, milk carton coatings; safe, clean and reusable, but not readily recyclable.

05 PP

Polypropylene (17%): food containers, drinking straws, nappies, DVD cases, vehicle bumpers, child seats; safe and heat-resistant, suited to recycling

06 PS

Polystyrene (5%): disposable tableware, expanded polystyrene packaging, insulating material; hazardous to health, especially when heated, easily recyclable into new plastic, obstacle: contamination and mixing

07 O

Other (31%): e.g. acrylic, nylon, polycarbonate for suitcases, CDs, clothing, ropes, parachutes, toothbrush bristles, toys, electrical appliance housings

Bio-recycling: bacteria breaking down plastics

Around 360 million tonnes of plastics are produced worldwide every year, about half of which ends up in landfills or in the environment.

Polyethylene terephthalate, or PET for short, is one of the most important plastics. Every year, around 70 million tonnes of PET are produced worldwide - for short-lived goods such as bottles, food containers or packaging, and also for long-lived goods such as textile fibres for sportswear, carpets, laboratory containers or medical prostheses.

In *conventional mechanical recycling,* the plastic is washed, shredded and melted. However, this cannot be continued indefinitely as this particular method used on a long term basis greatly reduces the quality of the plastic.

A start-up from the fictional city of Silvertown has developed a *new biotechnological recycling* process which might solve this problem.

In Silvertown, two **scientists** who recently founded a **start-up** are initially investigating bacteria in a landfill site. Fortunately, they discovered a new strain of bacteria which has developed enzymes that break down PET.

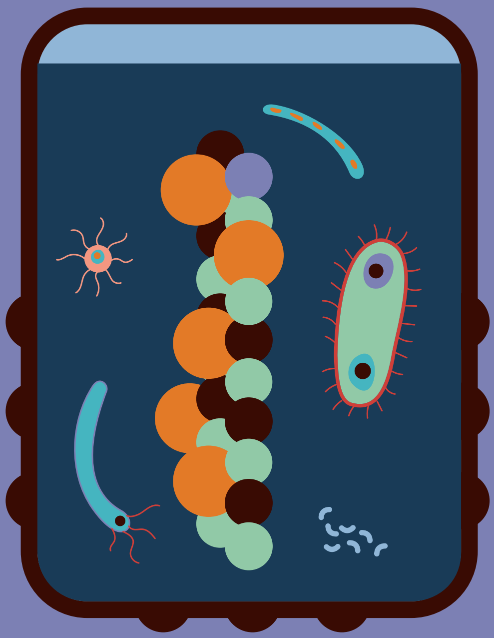
However, as plastic waste is usually not sorted by type but mixed with other types of plastic, the process currently only works with (pre-sorted) PET waste. The remaining plastic waste therefore continues to be incinerated or landfilled. Whether and when it will be possible to extend the process to other plastics waste remains to be seen.

Source: own presentation after Tournier et al. 2020[26]

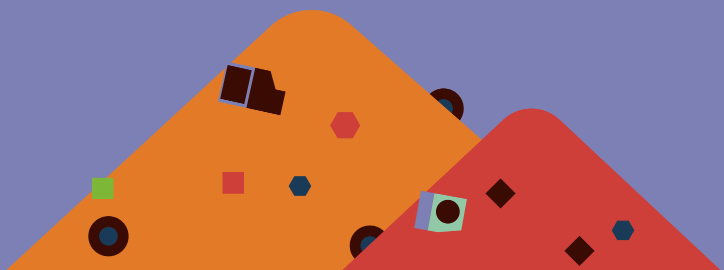
Using a bioreactor, they culture this novel bacterial enzyme which breaks PET back down into its original building blocks or monomers. These building blocks are key to high-quality recycling because they can be turned into new, high-quality plastic pellets which are of the same quality as the primary plastic. This is known as biotechnological recycling or bio-recycling for short.

The process is subjected to initial testing in a **real-world laboratory** which is funded by the city of Silvertown. Here, researchers from **universities**, small **companies** and **start-ups** can try out their innovations before they are put into practice. This encourages creativity and inventiveness and at the same time provides financial support to emerging companies.

The plastic pellets are offered for sale via the city's newly founded **recycling platform.** This is a kind of online marketplace where you can buy and sell the plastic pellets and plastics waste online. Thus, for the first time, infrastructure is being created to collect and reuse valuable secondary raw materials that are lying dormant in the urban stock.



A **manufacturer** of **outdoor clothing** sees this as an opportunity to create a new business model: Raw materials are saved by using the bio-recycling process to produce new items of clothing from old ones. PET ski trousers can become new ski trousers again and again with no loss of quality, so closing the clothing cycle loop. Furthermore, this eco-friendly behaviour helps to win new customers!



2.4 New business models: using instead of buying

"People want to own stuff, not share it. Cars have social significance, a fact that is exploited by advertisers."

Estimates suggest that in Germany alone there will be two to three million electric cars on the road by 2025.[27] E-batteries are among the "key technologies" which are crucial to the economies of Germany and of Europe as a whole. Their production requires costly, sometimes critical raw materials, including cobalt, lithium, nickel and copper. The EU has to buy most of these from abroad and is therefore dependent on third countries. As a result, whether from a strategic, economic or environmental standpoint, recycling is becoming an increasingly urgent issue. Recycling is still in its infancy, especially since e-batteries have a complex structure and are very difficult to dismantle. Scientists are working intensively to develop new methods which are already in existence for conventional car batteries. The business community has also hit upon a new business model which can provide greater sustainability. The illustration offers a first impression.

"We are often still only picking the 'low-hanging fruit': just recycling the shell of an electric car, but not the battery, achieves the target recycling rate."

So why isn't this already happening?

The illustration relates to a European manufacturing company which has piloted battery leasing for electric cars. However, this is a pioneering project and is not being used across the board. In addition, battery recycling is so complex that scientists around the world are researching new solutions. The obstacles are not only technical, but above all economic, as recycling does not yet offer great sales potential. However, the pioneering European company has identified one benefit of battery recycling: by doing so, it is offering an additional service and can differentiate itself from the competition by being more sustainable. If it's a hit with its customers, i.e. if end consumers increasingly opt for sustainable, recycled products, this pressure could encourage other car makers to become more innovative in terms of sustainability.

Still tearing around corners?

Did you know that vehicle tyre abrasion is a major cause of microplastics? Rubber particles are detached every time we accelerate, brake abruptly, or corner fast. These particles are usually microscopic, which is why they are referred to as microplastics. On European roads alone, half a million tonnes of material is abraded from tyres every year.[28] Even more serious for urban mining is the fact that old car tyres are hardly ever reused, with only a vanishingly small percentage of used tyres being retreaded.

2.5 New business models: treasure from the recycling centre

In the Stone Age, people hunted and gathered food and items that were important for survival. Today's bargain hunters often collect things they rarely use or don't use for long. On average, German households have well over 1,000 euros worth of unused items lying around.

The following illustration is based on a business model which is being tested in Germany and aims to remedy this problem with a new approach, which also involves appropriate reuse of items that are no longer in use. Above all, the business model is intended to encourage people to examine how and why they consume today, and how things might be done differently.

"Urban mining is not just recycling, but also repair and reuse.[i] We often forget that the biggest lever at our disposal is product reuse, which is where the biggest energy and resource savings could be made."

i How much and where something can be repaired or remanufactured depends crucially on local labour costs.

"As a consumer, I have market power. Otherwise, there wouldn't be organic supermarkets."

Using instead of buying: the electric car battery

An e-battery weighs around 700 kilograms and is extremely expensive. E-battery manufacture uses 40 per cent of the cobalt mined worldwide, the price of which has quadrupled in two years. Lithium is also needed for the battery and mostly comes from Bolivia and Chile.

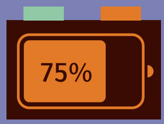
Once they have reached the end of their useful life, the lead-acid batteries previously used in conventional cars have often ended up in Africa, where they are reprocessed under questionable conditions and returned to Europe as “recycled” batteries.

Recycling which respects the environment and human dignity is necessary, but difficult. E-batteries are so complex that they are very difficult to break down into their individual components.

Here, too, the fictional city of Silvertown is taking an innovative approach.

Source: own presentation after Fraunhofer IWKS 2018,[29] recyclingnews 2020[30] and Seibt 2019[31]

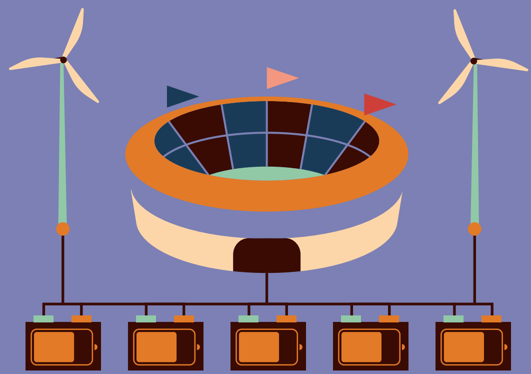
Firstly, software monitors an e-car's battery status in real time, i.e. "on the road".



Once the battery's capacity has dropped to below 75 per cent of its original level, it no longer meets the vehicle's requirements. The software sends a message that the battery is no longer suitable for the e-car.

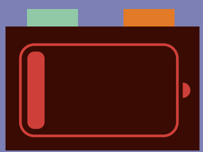
The **car owner** now drives to the nearest charging station and swaps the used battery for a new one.

However, the used battery is far from worthless. It can now enter the second phase of its life by being transferred to a stationary energy storage system in a football stadium.



The purpose of this energy storage system is to supply the stadium with sufficient electricity from renewable sources, such as solar or wind energy. If the weather changes and the wind and sun stop playing along or if demand spikes during a game, the e-battery steps in and balances the power supply.

Once the e-battery has reached the end of its service life after a total of 20 years, recycling is the next step.

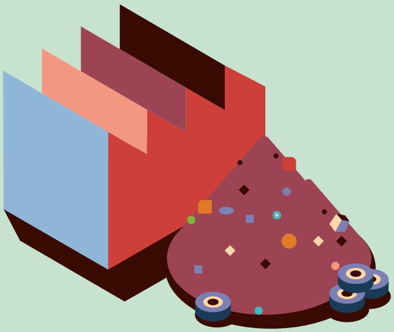


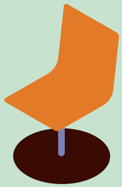
New business models:
treasure from the recycling centre

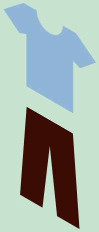
Clothes, books or tools - most of us have items at home that we no longer use. The value of these items which are lying around unused in every household in Germany amounts to around 1,000 euro.

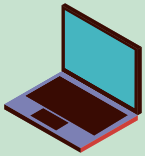
During spring cleaning or house moves, these items are often simply discarded and end up in the rubbish.

Here, too, the fictional city of Silvertown has an idea for a sustainable business model, because urban mining doesn't just involve recycling but also reuse and repair.

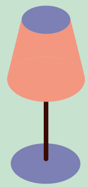








In Silvertown, the recycling centres and landfill sites of the **waste management department** receive many items which are still in good condition. Thus, the department would like to give them a second life.



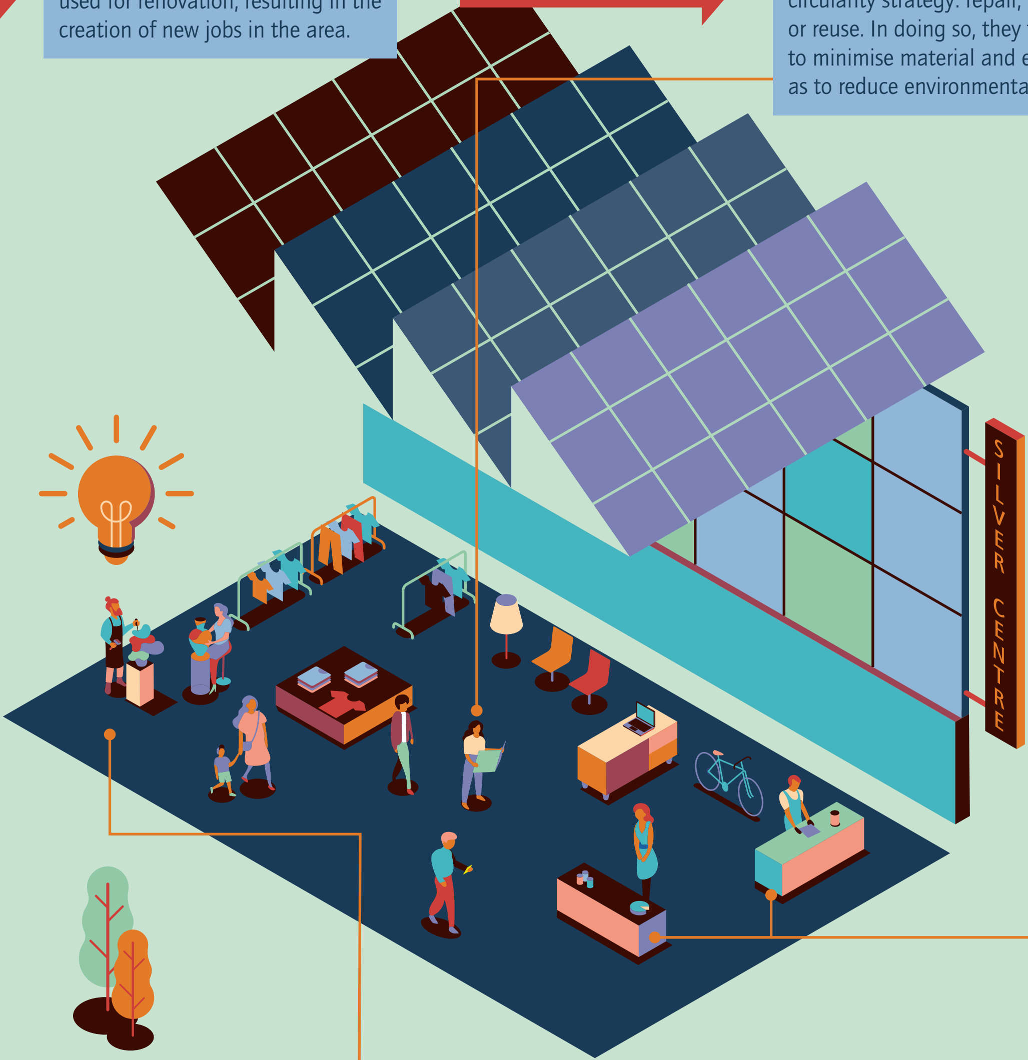
Their idea is to set up a department store, the so called **Silver Centre**, to sell any items received in good condition at a low price.

The Silver Centre becomes a place to experience sustainability, offering workshops and explaining to people of all ages how to consume sustainably and recycle in a high-quality way.

When the used goods have reached the end of their useful life, they end up back in the recycling centre or landfill site.

The Silver Centre is set up in a vacant industrial building. As far as possible, recycled materials are used for renovation, resulting in the creation of new jobs in the area.

Next, the Silver Centre hires **"circularity managers"** whose job it is to decide the best circularity strategy: repair, recycle or reuse. In doing so, they take care to minimise material and energy so as to reduce environmental impact.



In the department store, local residents can buy the reprocessed products, ranging from clothing to furniture and electrical appliances.

At the **repair café** skilled craftsmen repair broken objects on site for the city's inhabitants, who can pass the time with a fair-trade coffee and locally made cake.

Start-ups present new project ideas, such as turning old items from the recycling centre into new pieces of furniture or even works of art.

Source: own presentation after Berlin Waste Management (BSR) 2020[32]

2.6 Data mining with the material passport

Urban mining cannot exist without data mining. Recycling becomes difficult if it is not known which raw materials are present and where they are located. A building, electrical appliance or car includes countless different raw materials supplied by various manufacturers from different countries and this information tends to get lost over the years. As a result, waste products are taken to a recycling company or landfill site – yet valuable raw material data is missing. Dismantling an e-battery could even be hazardous to the environment and to health if the composition of the materials is unknown. It would therefore make sense for manufacturers to take responsibility for recycling (see Chapter 2.4). In the construction sector, too, it is important to document everything that goes into a building so that any harmful substances, such as toxic fire retardants in the building's insulation, can be removed during recycling (see Chapter 2.2). Experts are therefore proposing the introduction of a "material passport". Taking a car by way of example, the illustration shows what this might look like in the future.

"In a similar manner to the Circular Economy, in which packaging designers pre-emptively coordinate with waste management in the development of circular packaging, urban mining could also involve design managers and recycling companies working together from the outset and designing (durable) products so that they can ultimately be recycled. This, however, is not how a car is built."

From the European Green Deal to the material passport

Have you heard of the European Green Deal? It's a kind of roadmap for a sustainable EU economy. This involves a new strategy to help Europe achieve an environmentally friendly, resource-efficient and competitive economic model. One of many proposals put forward by the European Commission is the creation of a material passport which is intended to provide information "on a product's origin, composition, repair and dismantling possibilities, and end of life handling."[33] Germany could also endorse this approach and moreover advocate that information on critical pollutants be made available in the material passport.

A glimpse into the future: recycling-by-design

Often, when a product is being manufactured or a house built, little thought is given to what will happen to it in two, ten or thirty years' time, once repairs are due or it has reached the end of its useful life. Accordingly, all effort has to be put in developing a more sustainable solution. This is where recycling-by-design comes in: this approach involves architects, designers, developers and engineers addressing from the very outset how, years or decades later, we will most efficiently be able to sort, disassemble, i.e. deconstruct,[j] recycle and reuse raw materials. Especially with high-tech products and materials which are new to the market, there is now an opportunity to take recycling into account even before they are put into use.

So why isn't this already happening?

The simple answer is that there have not previously been any incentives to collect material data, store it centrally and make it transparently available to different stakeholders. This demonstrates how the idea of urban mining is still in its infancy. The complexity of data acquisition and maintenance is revealed by the size of the anthropogenic stock (see illustration, Chapter 1). This mammoth task has been undertaken by the German Environment Agency, which is already working on mapping the anthropogenic stock for the whole of Germany. To this end, a database is to be created in the coming years, basically a kind of giant material passport with over 300 categories of goods. However, the work is still far from complete: construction companies, cities, local authorities and manufacturers should already be starting to introduce material passports when manufacturing new products and infrastructure.

"Recycling companies have no data about products, for instance about a car. Car manufacturers are too worried that the data will fall into the wrong hands. However, without data about the individual material compositions that go into the car, recycling cannot be done efficiently."

"Today's product is tomorrow's raw material."

j A product's "deconstructibility", i.e. the ability to break it back down into its individual components, is an important prerequisite for recycling.

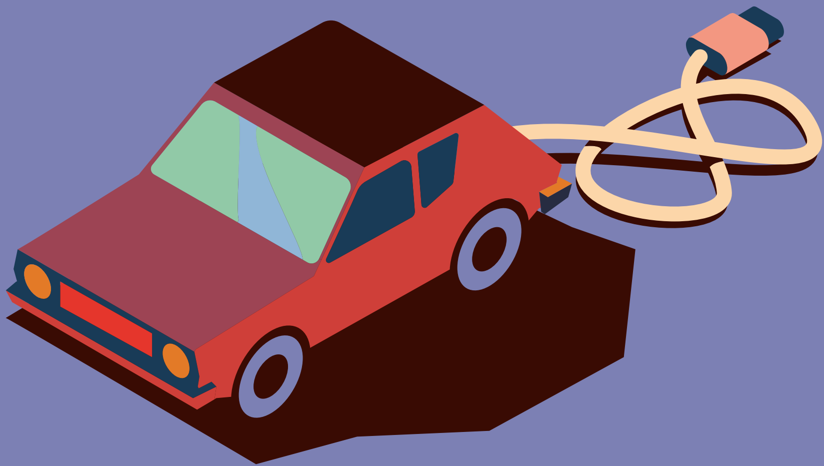
Urban mining is also data mining: the material passport

A car includes several thousand individual parts from suppliers in different countries. From the electronics to the bodywork to the engine/motor – there are many valuable raw materials everywhere.

So far, little thought has been given during production to what will happen to these raw materials in ten or twenty years' time. Car manufacturers are not very keen to share their material data. As a consequence, recycling companies lack raw material data and can't recycle efficiently.

In addition, over four million end-of-life vehicles disappear from Europe every year. This means that every year Europe loses millions of tonnes of plastics, steel and aluminium.

The fictional city of Silvertown has come up with something new here too.



Source: own presentation after Hansen & Schmitt 2020[34] and BAMB 2020[35]

A car manufacturer based in Silvertown would like to recycle more efficiently and settles upon the idea of a material passport for every car. All the materials used in production and subsequent maintenance are documented from the outset and transparently accessible in the passport.

When the car is recycled at the end of its life cycle, it is sent together with the material passport to the **recycling company**. Sorting robots read the information and then know which materials are present where in the car. As a result, the car can be very efficiently recycled and the raw materials return to the loop.

Whenever **car owners** have their cars repaired or parts replaced, this information is automatically transferred into the material passport, so keeping the data updated over the entire life cycle of the car.

This begins with recycling-by-design: before the car is produced, **developers** and **designers** consider how the individual components can best be separated during subsequent recycling. All of this information goes into a digital database – the material passport.

The entire production process is digitalised. This means that every single installed material part from all global **suppliers** goes into the material passport database.

When the car is sold, the car owner also gets access to at least some of the information in the material passport database.

It is important to keep sensitive information, i.e. individual product parts and their composition, confidential. Commercial secrets must not fall into the wrong hands.

This is where an independent institution comes into play, the **information trustee**, which manages the confidential, competition-critical data of the material passport and ensures that the data is protected. All the other information in the material passport is accessible to the relevant stakeholders.

3 International spotlight: Amsterdam and the doughnut model

Around the world, there are already a number of pilot projects which are attempting to demonstrate that urban mining is not just a nice concept on paper but can lead to exciting business ideas in reality. One of these has been developed in the Netherlands.

Amsterdam's goal is to become the first city in the world to be 100 per cent circular by 2050.[36] This goal was inspired by the doughnut model devised by the British economist Kate Raworth from Oxford. The focus here is not only on economic performance, but also on quality of life and sustainability. The model can be illustrated by a doughnut: the inner doughnut ring contains the foundational needs of society, which are aligned with the United Nations' Sustainable Development Goals including sufficient and nutritious food, clean water, shelter, sanitation, energy, education, health, gender equality, income and political participation. People living below these minimum standards are in the empty hole in the middle of the doughnut. The outer ring represents the ecological limits, i.e. resources, climate, soil, oceans, ozone layer, water and biodiversity. The dough of the doughnut between the outer and inner rings represents the goal, which is the location where the needs of society and nature meet and live in harmony.

However abstract this model may sound, Amsterdam's city council formally adopted the doughnut model as the starting point for policy decisions last year. This makes it the first city in the world to make such a commitment. "I think it can help us overcome the effects of the [coronavirus] crisis", says Amsterdam's deputy mayor Marieke van Doornick.[37] The coronavirus pandemic was a wake-up call for Amsterdam: the city was forced to confront the problems of climate, health, jobs, housing and care, and set out to find new solutions that could help to address these issues.

By the recent construction of a business park, Amsterdam has already demonstrated that this is not simply some, in van Doornick's words, hippie theory. This shows that an economic model based on growth, sustainability and circularity is, at least to some extent, also feasible in practice. The following illustration[k] shows how the model might work.

Regulation and innovation: pretty much best friends?

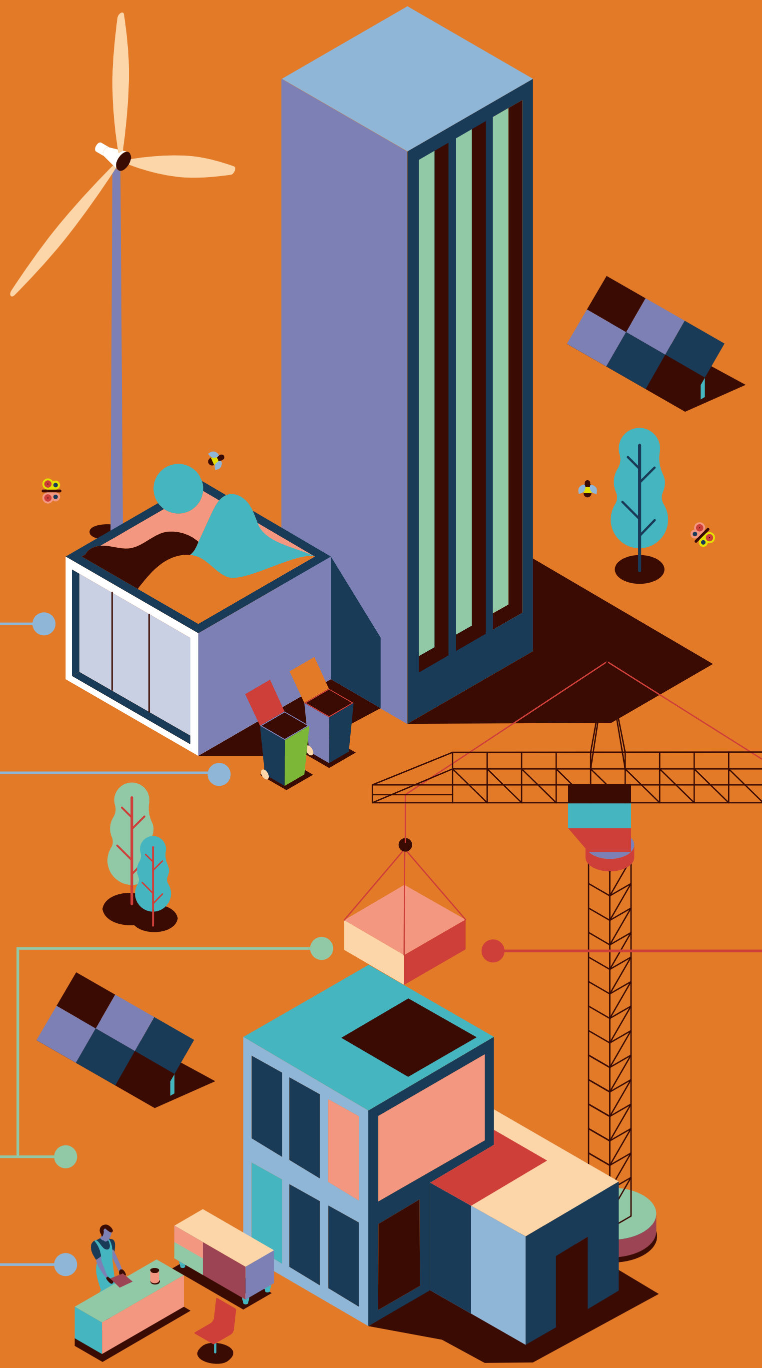
Pollutants from industry have been causing problems for humanity since as long ago as the 19th century. Even then, the urgency to protect the environment was countered by the fear that (strict) environmental regulation would stifle business competitiveness. In the 1980s, the economist Michael Porter attempted to break through the *ecology versus economy* paradigm and, on the basis of empirical studies, he concluded that environmental regulations can even stimulate innovation.

One example: in the past, the Dutch flower industry contaminated soils and groundwater with pesticides, herbicides and fertilisers. Policy makers then decid-ed to regulate the use of chemicals. This regulatory pressure forced the flower industry to come up with a new business model: they stopped planting flowers in soil and started using water and rock wool instead. This minimises pest infestation and thus the use of chemicals, which are additionally transported in the water and constantly reused, remaining in a closed, safe loop. As a result, environmental impact and costs have fallen while quality, customer satisfaction and global competitiveness have risen.[38]

k Although the illustration is based on the recently built business park in Amsterdam, it still represents an ideal case. In fact, there are many challenges which still stand in the way of completely closed-loop management, in particular of buildings (see Chapter 2.2)

Silver Valley – the sustainable business park

The construction sector is responsible for one third of Europe's CO_2 emissions and generates the most waste. The fictional city of Silvertown, together with private investors, has come up with a circular business model for a new business park with the aim of using recyclable materials for as long as possible and creating closed loops for materials, energy and water. This concept is already being initially tested in the Netherlands.



Reuse, renovation and recycling

The business park organises the reuse and renovation of old furniture instead of sending it to landfill.

A database records the location of each material in the building, each building having a material passport.

The majority of the materials are designed in such a way that they can easily be broken down into their individual components for recycling.

Environmentally and health-friendly materials

Wooden furniture is not treated with harmful chemicals but instead with natural substances such as vinegar. This allows the wood to be safely returned to nature.

Invitations to tender for new works are not based on the lowest price, but on certain quality features. For instance, substances which are less harmful to health and the environment must be used.

Source: own presentation after BetterWorldSolutions[39]

Responsible water use and design with nature

A rainwater system provides water for toilets and for watering green areas.

Farmers grow food in greenhouses and supply fresh fruit and vegetables to Silver Valley restaurants, meeting at least some of the Silver Valley's food requirements. The greenhouses are heated with renewable energies, specifically with gas from the wastewater treatment plant.

The business park's gardens contain greenery, fresh vegetables and fruit, creating biodiversity.

Landscaping and plants in the park provide food and breeding sites for critically endangered butterfly species and bees, promoting biodiversity.

Social justice

Construction material manufacturers and suppliers no longer sell their goods, but lease them. Once a building has been deconstructed, they thus bear the responsibility for clean recycling. This keeps the cost of acquisition, and thus the price, of buildings low.

One important prerequisite for recycling is to tax primary raw materials while in return cutting labour taxes. This makes the extraction of new raw materials more expensive and, at the same time, recycling more financially attractive for manufacturers and suppliers.

Renewable energies

Integrated solar cells are installed in the windows of the glazed office buildings, generating solar energy and providing sufficient shade for the buildings in summer.

Solar panels and wind turbines generate electricity from renewable sources throughout the site, so that at least some of the electricity demand is met.

4 From rhetoric to implementation: the stakeholder cycle

What needs to happen now? The previous chapters have highlighted the trailblazing achievements of some pioneers. The final illustration summarises the options avail-able to academia, business, policy makers and society. Only if all stakeholders pull together can urban mining succeed across the board.

“Practical implementation is where the main difficulty lies: experience is vital to demonstrate that urban mining can also be economically successful. We ought to simply try it out and also keep on going even if there isn’t an immediate ‘quick win’.”

The success of urban mining depends above all on the people who drive the issue forward. Because the best study and the latest recycling technology are of no use if they end up gathering dust in some research institution. The most innovative start-up idea for a sustainable business model will fizzle out if no investor believes in it. The most environmentally friendly product will not make it to market if the political framework is lacking.

The following illustration summarises what policy makers, business, academia and consumers can do in concrete terms. In a similar way to a loop or cycle in which raw materials are continually reused, there is also a stakeholder cycle.

Urban mining can only work if all those involved think and act together and move towards their goal of achieving a balance between people, technology and nature.

“The thing that is not circular is time.”

The stakeholder cycle

Policy makers creating the framework

Economic incentives (carrot): encourage innovation by companies, reward the use of recycled goods, provide incentives for companies to recruit staff for circular activities (including recycling and repair)

Disincentives (stick): introduce raw materials tax, initially on sand and gravel, to make recycled concrete financially attractive (this is being tested in the Netherlands, see illustration Chapter 3); EU "plastics tax" on non-recycled plastics (set to come into force from 2021)

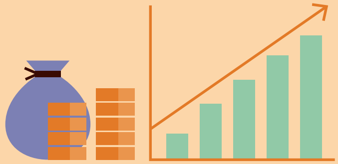
Introduce **material passport** with information about material components for all products. An independent trustee manages the data confidentially and guarantees data protection.

Safe-by-design: avoid pollutants as much as possible and replace them with degradable materials that can be returned to nature

Release the tiger: take risks and back disruptive recycling technologies in close coordination with scientists; healthy competition to produce the most sustainable products

Develop **new business models** including new recycling platforms for trading recycled materials and more leasing-models. A manufacturer must always bear the responsibility for clean recycling when leasing.

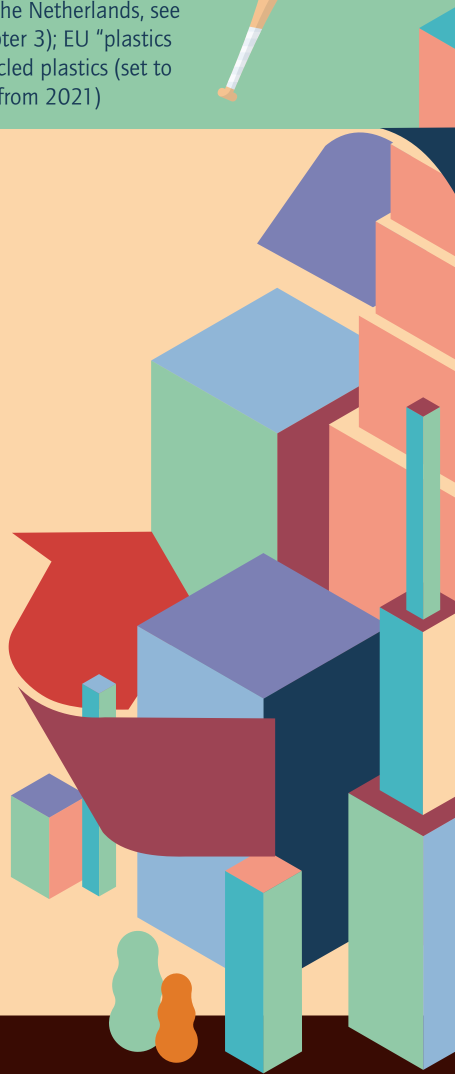
Business



Endurance: no quick wins as purchase costs are high

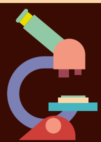
Recycling by design: take account of recycling from the outset to improve sorting, recycling and repair of all end-of-life products without exception

Global competitiveness through **responsible entrepreneurship:** German and European companies can differentiate themselves from international competitors by manufacturing environmentally and health-sensitive products under decent working conditions.



The foundation: science and research

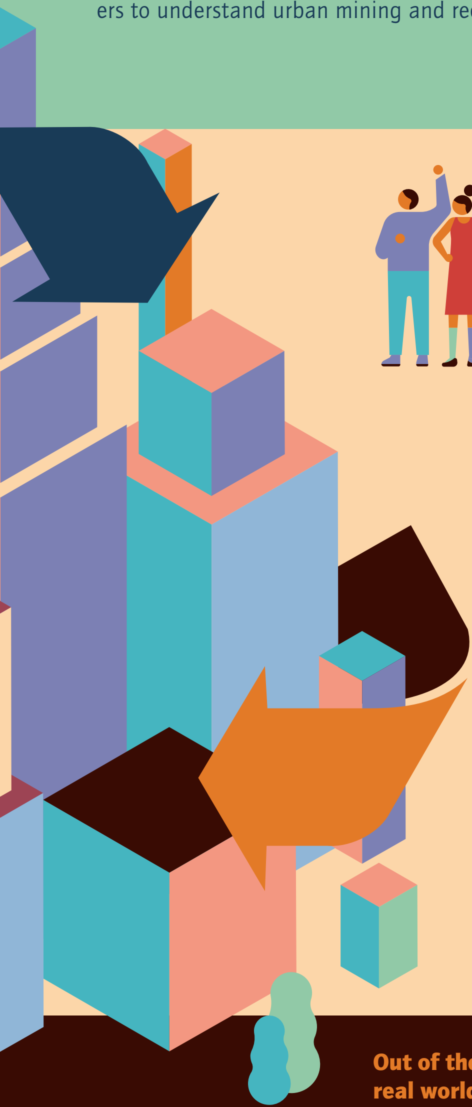
Researching **new, environmentally friendly materials** and new **recycling technologies**



Source: own presentation

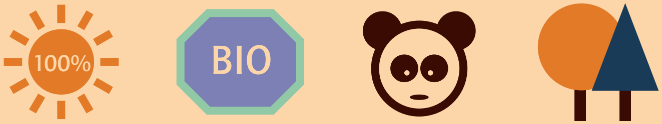
Awareness-raising and education: promote interdisciplinary study programmes and mindset; train designers, materials researchers, business economists and developers to understand urban mining and recycling

Material passport: must be introduced for all buildings and infrastructure to keep constant track of the location of materials



Society

Eco-label: as consumers, pay more attention to eco-labels with information on environmentally friendly, recycled materials. There are already individual (voluntary) initiatives, such as the RAL quality mark for recycled plastics and recycled building materials and Blue Angel or building certification schemes that assess the sustainability of buildings.

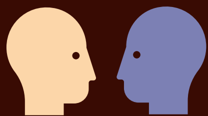


Mindset: consume differently, use instead of buy, repair, reuse and recycle more; be more aware of environmental compatibility and the working conditions under which products are manufactured

Purchasing behaviour as market power: as consumers, place more value on sustainability and thus exert pressure on companies. More sustainable products are increasingly displacing the less sustainable from the market.

Out of the laboratory into the real world: close coordination with companies to test recycling technologies in pilot projects

Raise awareness of policy makers, business and society; communicate results to the public transparently and realistically



Interviewees

The project group (page 47) determined the content of this publication. acatech conducted a total of 18 interviews with experts from academia, business, policy makers and society. The interviews took place between June and November 2020. Some key ideas expressed by interviewees are included in the text as anonymised quotes.

The acatech Executive Board would like to thank all experts sincerely for their participation in the interviews! In detail these were:

Dr. rer. nat. Katrin Bokelmann, Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS

Prof. Dr. Magnus Fröhling, Chair of Circular Economy, Technical University of Munich

Dr.-Ing. Andrea Gassmann, Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS

Prof. Dr. Kathrin Greiff, Institute for Anthropogenic Material Cycles, RWTH Aachen

Prof. Dr. Erik Hansen, Head of Endowed Institute for Integrated Quality Design (endowed by Quality Austria – Trainings, Zertifizierungs und Begutachtungs GmbH and the Province of Upper Austria), Johannes Kepler University Linz

Benjamin Hein, Head of Business Unit Development Circular Economy, DIN e. V.

Prof. Dr. Manfred Hennecke (head of project group), President (ret.), Federal Institute for Materials Research and Testing

Hermann Keßler, Head of Resource Conservation, Material Cycles, Mineral and Metal Industry Section, German Environment Agency

Prof. Dr. Hans-Joachim Kümpel, President (ret.), Federal Institute for Geosciences and Natural Resources, honorary member of Verband Bergbau, Geologie und Umwelt e.V.

Dr. Christine Lemaitre, Managing Director, Deutsche Gesellschaft für Nachhaltiges Bauen e.V. (German Sustainable Building Council)

Dr. Guido Meurer, Member of the Board of Management, BRAIN AG

Prof. Dr. Frank Mücklich, Chair of Functional Materials, Saarland University

Stephanie Otto, Chairwoman of the Board of Management, Berliner Stadtreinigung

Dr. Carsten Polenz, Vice-President, SAP SE

Dr. Bettina Rechenberg, Head of Division III, Sustainable Production and Products, Waste Management, German Environment Agency

Christian Schiller, Co-Founder and CEO, cirplus GmbH

Prof. Dr. Franz-Georg Simon, Contaminant Transfer and Environmental Technologies, Federal Institute for Materials Research and Testing

Dr. Volker Thome, Head of department of Mineral Materials and Building Material Recycling, Fraunhofer Institute for Building Physics IBP

Contributors

Overall management of acatech HORIZONS:

Prof. Dr.-Ing. Jürgen Gausemeier, Vice-President acatech, Senior Professor at Paderborn University's Heinz Nixdorf Institute

Innovation forum lead:

Prof. Dr. Martina Schraudner, acatech board member, Head of Fraunhofer Centre for Responsible Research and Innovation

Urban Mining project group:

Dr. rer. nat. Katrin Bokelmann, Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS

Prof. Dr. Magnus Fröhling, Chair of Circular Economy, Technical University of Munich

Dr.-Ing. Andrea Gassmann, Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS

Prof. Dr. Erik Hansen, Head of Endowed Institute for Integrated Quality Design (endowed by Quality Austria – Trainings, Zertifizierungs und Begutachtungs GmbH and the Province of Upper Austria), Johannes Kepler University Linz

Prof. Dr. Manfred Hennecke (head of project group), President (ret.), Federal Institute for Materials Research and Testing

Prof. Dr. Hans-Joachim Kümpel, President (ret.), Federal Institute for Geosciences and Natural Resources, honorary member of Verband Bergbau, Geologie und Umwelt e.V.

Dr. Christine Lemaitre, Managing Director, Deutsche Gesellschaft für Nachhaltiges Bauen e.V. (German Sustainable Building Council)

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Christian Schiller, Co-Founder and CEO, cirplus GmbH

Dr. Volker Thome, Head of department of Mineral Materials and Building Material Recycling, Fraunhofer Institute for Building Physics IBP

Content design, creation of text and graphics:

Christina Müller-Markus, acatech Office, HORIZONS (lead author)

Assisted by:

Violeta Helling, acatech Office, HORIZONS

Marco Mitrovic, acatech Office, HORIZONS

Laura Grewe, acatech Office, HORIZONS

Vivian Würf, acatech Office, HORIZONS

Sebastian Grünwald, acatech Office, HORIZONS

Bibliography

1. Hornberg, C. (2020): Umweltgutachten 2020: Für eine entschlossene Umweltpolitik in Deutschland und Europa. https://www.umweltrat.de/SharedDocs/Downloads/ DE/01_Umweltgutachten/2016_2020/2020_Umweltgutachten_ Entschlossene_Umweltpolitik.pdf

2. Müller, F., Lehmann, C., Kosmol, J., Keßler, H., Bollan, T. (2017): Urban Mining. Ressourcenschonung im Anthropozän. Umweltbundesamt. https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/uba_broschuere_urbanmining_rz_screen_0.pdf

3. Hansen, E., Wiedemann, P., Fichter, K., Lüdeke-Freund, F., Jäger-Erben, M., Schomerus, T., Alcayaga, A., Blomsma, F., Tischner, U., Ahle, U., Büchle, D., Denker, A., Fiolka, K., Fröhling, M., Häge, A., Hoffmann, V., Kohl, H., Nitz, T., Schiller, C., Tauer, R., Vollkommer, D., Wilhelm, D., Zefferer, H., Akinci, S., Hofmann, F., Kobus, J., Kuhl, P., Lettgen, J., Rakowski, M., von Wittken, R. and Kadner, S. (2020): Circular Business Models: Overcoming Barriers, Unleashing Potentials. acatech/Circular Economy Initiative Deutschland/SYSTEMIQ. https://www.acatech.de/publikation/circular-business-models-overcoming-barriers-unleashing-potentials/

4. Zech, T. (2018): Stadt und Land: eine Beziehungsgeschichte. deutschland.de. https://www.deutschland.de/de/topic/leben/stadt-und-land-fakten-zu-urbanisierung-und-landflucht

5. Forti, V., Baldé, C., Kuehr, R., Bel, G. (2020): The Global E-waste Monitor 2020. Quantities, flows, and the circular economy potential. United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA). http://ewastemonitor.info/wp-content/uploads/2020/07/GEM_2020_def_july1_low.pdf

6. BRAIN AG: BRAIN BioXtractor. Nachhaltige Metallgewinnung in der Kreislaufwirtschaft. https://www.brain-biotech.com/de/bioxtractor

7. Bitkom (2018): 124 Millionen Alt-Handys liegen ungenutzt herum. Bitkom. https://www.bitkom.org/Presse/Presseinformation/124-Millionen-Alt-Handys-liegen-ungenutzt-herum.html

8. Hansen, E. G., Revellio, F. (2020): Circular value creation architectures: Make, ally, buy, or laissez-faire. Journal of Industrial Ecology, 24(6):1250–1273.

9. Widmer, C. (2019): Das steckt in einem Smartphone. Swisscom Magazin. https://www.swisscom.ch/de/magazin/digitalisierung-im-alltag/gold-rohstoffe-smartphone/

10. Fraunhofer Gesellschaft (2018): Neuartiges Recycling von Bauschutt. Fraunhofer Gesellschaft. https://www.fraunhofer.de/de/presse/presseinformationen/2018/oktober/neuartiges-recycling-von-bauschutt.html

11. Bundesministerium für Wirtschaft und Energie (BMWi) (2020): Rohstoffstrategie der Bundesregierung. Sicherung einer nachhaltigen Rohstoffversorgung Deutschlands mit nichtenergetischen mineralischen Rohstoffen. https://www.bmwi.de/Redaktion/DE/Publikationen/Industrie/rohstoffstrategie-der-bundesregierung.pdf

12. Schipper, O. (2020): Beton aufwerten und das Klima schonen. ETH Zürich. https://ethz.ch/content/main/de/news-und-veranstaltungen/eth-news/news/2020/08/kohlendioxid-binden-mit-betonbruch.html

13. Stadt Zürich Hochbaudepartement (2019): Stadt Zürich erhält den ersten Preis für nachhaltiges Bauen. https://www.stadt-zuerich.ch/hbd/de/index/ueber_das_departement/medien/medienmitteilungen/2019/september/190925a.html

14. European Chemicals Agency ECHA: Candidate List of substances of very high concern for Authorisation. https://www.echa.europa.eu/candidate-list-table

15. Safe by Design: A safe future starts now. Chemicals. https://safe-by-design-nl.nl/home+english/chemicals/default.aspx

16. Deutsche Gesellschaft für Nachhaltiges Bauen – DGNB e.V. (2019): Gebäudekonzepte und Zertifizierungen: Es grünt so grün im Label. https://www.dgnb. de/de/aktuell/presse/?we_objectID=47664

17. Bundesministerium des Innern, für Bau und Heimat (2018): Bewertungssystem Nachhaltiges Bauen für Bundesgebäude (BNB). https://www.bnb-nachhaltigesbauen.de/bewertungssystem.html

18. Astor, M., Klaus, C., Grünwald, C. (2020): Foresight-Prozess III im Auftrag des BMBF. Zukunftsbüro des Bundesministeriums für Bildung und Forschung (BMBF). https://www.vorausschau.de/files/Foresight2020_50_Themenblaetter.pdf

19. ambista, Koelnmesse GmbH (2020): Nachhaltiges Design: Möbel aus Müll. https://www.ambista.com/de/magazin/nachhaltiges-design-moebel-aus-muell

20. Busse, L., Rechenberg, B. (2019): Kunststoffe in der Umwelt. Umweltbundesamt. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/190515_uba_fb_kunststoffe_bf.pdf

21. Schiller, C.: A Closer Look at the Circular Plastics Economy — Episode #1. Will the petrochemicals embrace the change or fight it? Medium. https://medium.com/@christian.schiller/a-closer-look-at-the-circular-plastics-economy-episode-01-229711245e03

22. Europäischer Rat (2020): Außerordentliche Tagung des Europäischen Rates (17., 18., 19., 20. und 21. Juli 2020)–Schlussfolgerungen. https://www.consilium.europa.eu/media/45136/210720-euco-final-conclusions-de.pdf

23. acatech – Deutsche Akademie der Technikwissenschaften e. V. (2018): CCU und CCS – Bausteine für den Klimaschutz in der Industrie. acatech POSITION. https://www.acatech.de/publikation/ccu-und-ccs-bausteine-fuer-den-klimaschutz-in-der-industrie-analyse-handlungsoptionen-und-empfehlungen/

24. Fuhr, L., Buschmann, R., Freund, J. (2019): Plastikatlas. Daten und Fakten über eine Welt voller Kunststoff / 4. Auflage. Heinrich Böll Stiftung, Bund für Umwelt und Naturschutz Deutschland (BUND). https://www.boell.de/de/2019/05/14/plastikatlas?dimension1=ds_plastikatlas

25. Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik UMSICHT (2020): Grundlagen zu Polymeren und Kunststoff. https://www.umsicht.fraunhofer.de/de/ueber-fraunhofer-umsicht/nachhaltigkeit/nationale-informationsstelle-nachhaltige-kunststoffe/polymere-kunststoff/grundlagen.html

26. Tournier, V., Topham, C.M., Gilles, A. et al. (2020): An engineered PET depolymerase to break down and recycle plastic bottles. Nature, (580):216–219.

27. Fraunhofer-Einrichtung für Wertstoffkreisläufe und Ressourcenstrategie IWKS (2019): Kreisläufe in der Elektromobilität schließen. Batterierecycling in der Elektromobilität. https://www.iwks.fraunhofer.de/de/iwks-abteilungen/Energiematerialien/Batterien-und-PV-Module/batterierecycling.html

28. James Dyson Foundation (2020): The Tyre Collective - capturing micro-plastic pollution from tyre wear. https://www.youtube.com/watch?v=ZFreX8pJiG4

29. Fraunhofer-Einrichtung für Wertstoffkreisläufe und Ressourcenstrategie IWKS (2018): Verbundprojekt »AutoBatRec2020« gestartet. https://www.iwks.fraunhofer.de/de/presse-und-medien/pressemitteilungen-2017/autobatrec2020-altbatterien-aus-e-fahrzeugen-intelligent-wiederverwerten.html

30. recyclingnews, ALBA Group plc & Co. KG (2020): Mieten statt kaufen: Renault schließt den Batteriekreislauf. Renault-Vorstandsmitglied Martin Zimmermann im Interview. https://www.recyclingnews.de/rohstoffe/mieten-statt-kaufen-renault-schliesst-den-batteriekreis lauf/

31. Seibt, T. (2019): Neue Techniken sind nötig. auto motor sport. https://www.auto-motor-und- sport.de/tech-zukunft/alternative-antriebe/fraunhofer-positionspapier-elektroauto-batterie-recycling /

32. Berliner Stadtreinigung BSR (2020): BSR-Gebrauchtwarenkaufhaus "NochMall" eröffnet. Kombination aus Secondhand-Kaufhaus und Nachhaltigkeits-Zentrum. https://www.bsr.de/bsr-gebraucht warenkaufhaus-noch-mall-eroffnet-27982.php

33. Europäische Kommission (2019): MITTEILUNG DER KOMMISSION AN DAS EUROPÄISCHE PARLAMENT, DEN EUROPÄISCHEN RAT, DEN RAT, DEN EUROPÄISCHEN WIRTSCHAFTS-UND SOZIALAUSSCHUSS UND DEN AUSSCHUSS DER REGIONEN. Der europäische Grüne Deal. https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0021.02/DOC_1&format=PDF

34. Hansen, E. G., Schmitt, J.C. (2020): Orchestrating Cradle-to-Cradle Innovation Across the Value Chain: Overcoming Barriers through Innovation Communities, Collaboration Mechanisms, and Intermediation. Journal of Industrial Ecology, 1-21, doi: https://doi.org/10.1111/jiec.13081.

35. Buildings as Material Banks (BAMB) (2020): Materials Passports. https://www.bamb2020.eu/topics/materials-passports/

36. StoneCycling (2020): Amsterdam to Become First Circular City in the World. https://www.stonecycling.com/news/amsterdam-circular-city

37. Boffey, D. (2020): Amsterdam to embrace 'doughnut' model to mend post-coronavirus economy. Dutch officials and British economist to use guide to help city thrive in balance with planet. the Guardian. https://www.theguardian.com/world/2020/apr/08/amsterdam-doughnut-model-mend-post-coronavirus-economy

38. Porter, M., van der Linde, C. (1995): Green and Competitive: Ending the Stalemate. Harvard Business Review. https://hbr.org/1995/09/green-and-competitive-ending-the-stalemate

39. BetterWorldSolutions: First Cradle-To-Cradle Business Park In The Netherlands. BetterWorldSolutions. https://www.betterworldsolutions.eu/first-cradle-to-cradle-business-park-in-the-netherlands/

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Further information: https://en.acatech.de/

PUBLISHER:
acatech – National Academy of Science and Engineering

OFFICE ADDRESSES
Munich Office
Karolinenplatz 4
80333 Munich, Germany
T +49(0)89 / 520309-0
F +49(0)89 / 520309-900

Berlin Office
Pariser Platz 4a,
10117 Berlin, Germany
T +49(0)30 / 2063096-0
F +49(0)30 / 2063096-11

Brussels Office
Rue d'Egmont / Egmontstraat 13,
B-1000 Brussels, Belgium
T +32(0)2 / 2 13 81-80
F +32(0)2 / 2 1381-89

horizonte@acatech.de
https://en.acatech.de/project/acatech-horizons-overview/

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Layout, typesetting and illustrations:
Joseph & Sebastian – Graphic design, Munich

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Paul Clarke & Charlotte Couchman, Lodestar Translations
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The earth's resources are finite. If we use them wastefully, they will not be able to sustain humanity in the long term. Nevertheless, anything that has reached the end of its useful life is very often thrown away after a short time. This is precisely where urban mining comes in: instead of mining more and more primary materials, the aim is to consistently reuse the stocks of secondary materials which have previously lain unused in cities and settlements. These materials range from building materials to the precious metals in electronic parts to plastics, which until now have often been thrown away. This is partly due to a lack of the data required to locate, reprocess and recycle them. But what are the barriers and how can they be overcome? What is the current state of play and just what will be possible in the future? This issue of HORIZONS focuses on these and other fascinating questions.