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# The Need for Final Sinks

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The man made turnover of materials has tremendously increased during the last 200 years. As a consequence, two issues have become of prime concern in the 20ieth century: resource availability, and emissions into the environment. Resource use and environmental loadings are linked to each other, which is best illustrated by global warming: the large input of fossil fuel carbon into the anthroposphere results in a similarly large output of carbon dioxide. The accumulation of THG emissions in the sink atmosphere is a key driver for climate change.

Cities are hot spots of material turnover because of the high density of people with their needs for materials and energy. Also, they are the fastest growing settlements on a global scale: it is estimated, that in 1900 urban-dwellers made up only 13% of the global population. In 2005 49% of the world population lives in cities, and this fraction is expected to increase to 60% in 2030 (United Nations, 2008).
In general, the "metabolism" of a city depends entirely on the so called "Hinterland": all material resources are imported, and most of the wastes and off-gases are exported. While the supply of goods to cities is mostly controlled by market systems, the disposal depends more on regulation and technical and natural attenuation processes. Hence, cities are vulnerable on both sides of their "metabolic system": their sustenance and growth may be limited by insufficient supply at the front side e.g. of water, fuel, and food, and they may be limited by the possibilities to dissipate materials at the back end of the urban system. The latter is one reason why many former cities have been developed along large river systems allowing to use the dilution principle not only for off-gases but also to dispose of their solid and liquid wastes.
During the course of history, many cities faced the problem of limiting sinks regarding their wastes. The first such collection and treatment systems have been established more than 2000 years ago. During the nineteenth century, it became common knowledge that a healthy city needs a waste water collection and treatment system, and in the twentieth century, such systems have been established in all cities of world rank. A key person driving this metabolic view of cities was Abel Wolman who states in his famous publication on the "The Metabolism of Cities": " … the need for sinks, where materials can be disposed of in an appropriate way, i. e. without endangering the environment" (Wolman, 1968). He pointed out that, without having appropriate sinks, the environmental system could eventually become overloaded by the output of urban activities.
Today, with Megacities having a population exceeding 10 million inhabitants, and a material turnover of more than 200 tons per capita and year, the question arises if such intense metabolic systems are limited by the availability of sinks in water, air, and soil. The focus lies not on the traditional issues of waste and waste water treatment or air and soil pollution control. The centre of attention is an integral assessment of entire substance flows from a city over time, comprising classical emissions as well as emissions resulting from the use of materials like e.g. erosion and weathering processes of city surface materials, of public and private vehicles, and of processes for energy conversion. In addition, the pathways to the environment and the accumulation or depletion of materials in water, air, and soil have to be taken into account. Methods to evaluate these flows in view of constraints for urban development must be developed.

There are several past and present examples of substances that have been restricted in their use due to limited availability of sinks:

- The use of DDT as a pesticide was phased out because it resulted in the accumulation of DDT in the sink "biosphere" finally causing serious effects for certain wildlife (bird eggs with shells too brittle to survive).

- The use of certain halogenated hydrocarbons (CFCs) was banned because they accumulate in the sink "stratosphere". This build up has a destructive effect on the ozone layer that protects the earth surface from excessive UV radiation which can harm biological organisms such as plants, animals and humans.
- The large scale use of fossils fuels as well as other anthropogenic activities (land-use and agriculture) result in huge amounts of greenhouse gas emissions such as $CO_2$ and $CH_4$, consequently increasing the concentration of these gases in the sink "atmosphere" with implications for global climate. Measures to curb the use of fossil carbon are discussed on the global level.
- Due to the fact that mercury is toxic and accumulates, among others, in the sink biosphere, the European Commission has proposed to ban exports of elemental mercury from the European Union by 2011. In the US, the Congress has passed the "Mercury Export Ban Act of 2008" that will prohibit the commercial export of elemental mercury by 2013.
- These examples show clearly, that 1. a lack of appropriate sinks for certain substances has already been documented, and 2. that on a national as well as global level mechanisms to control certain substances that lack of an appropriate sink are developed. Thus, it is urgent to address the sink issue on a city level because this is the level of highest densities of material flows and stocks.

As of today, the term "sink" is a vague concept despite some excellent literature on this issue (Tarr, 1996). Thus, definitions of the expressions "sink" and "final sink" must be improved in order to make it operational for environmental protection, for urban planning and for resource management. Man-made flows of several elements of the periodic table surpass geogenic flows (Klee and Graedel, 2004), indicating that anthropogenic activities interfere with natural processes on a large scale. It is necessary to investigate in as far as this interference leads to elevated concentrations in water air and soil.

During the past 10.000 years, many cities have been destroyed by natural and manmade disasters, disappearing temporarily or forever. From a material point of view, this implies that most resources brought into the city have been released from the city, be it as contribution to the local soil, or to the "conveyor belts" water and air which transport these materials over short and long distances. In addition to material flows due to disasters, there are losses of materials from urban activities during their "regular" operations, such as nutrients form the activity "to nourish", metals from the activities "to transport" and "to reside", persistent organic chemicals from the activity "to clean" etc. (Baccini and Brunner, 1991; Baccini and Bader, 1996). All these materials have to be collected, treated and – if not transformed - ultimately exported from the city, and they have to be directed to appropriate sinks where they exert no negative effect for long time periods. Recycling is an appropriate strategy to minimize resource consumption and hence the need for sinks during resource extraction, production, consumption and waste disposal. However, a) the loss of substances during recycling cannot be completely prevented due to thermodynamic reasons, and b) most substances have to be disposed of in a final sink after the "last possible cycle". Hence, also a society that is based on circular use of materials will need sinks.

As a working hypothesis, a "sink" for a material flow from a city can be a conveyor belt such as water or air that transports materials out of the city boundaries, it can be a transformation such as an incinerator that completely mineralizes organic substances, and it can be a storage process such as a landfill where substances are disposed of. In contrast, the working hypothesis for a "final sink" denominates a place on the planet where a particular substance has a residence time of >10.000 years. It may consist of an underground salt mine, an ocean sediment or a place on the globe where sedimentation processes prevail erosion processes. For organic substances, a "final sink" may also be a transformation or mineralization process. A systematic approach to define and identify appropriate sinks and final sinks for specific substances of the urban metabolism represents a new challenge for research. Hopefully, many researchers will engage in this fascinating and rewarding interdisciplinary project.

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