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To Prospect an Urban Mine – Assessing the Metal Recovery Potential of Infrastructure “Cold Spots” in Norrköping, Sweden

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Abstract

In conventional mining, prospecting methods are used to increase the degree of certainty with regard to the stock of metals. Similarly, prospecting in terms of “urban mining” aims to increase the information about metal stocks available for recovery in the built environment. Infrastructure systems, such as for power supply and heating, are rich in copper, aluminum and iron (including steel). For a number of reasons, pipes and cables remain in the ground after being taken out of use or disconnected. This is also true for entire obsolete systems. In this paper, these infrastructures “cold spots” are viewed as hibernating stock with a significant potential for urban mining.

The infrastructure systems for AC and DC power, telecommunication, town gas and district heating in the city of Norrköping, Sweden, have been quantified and spatially allocated with a GIS-based approach of Material Flow Analysis (MFA). About 20% of the total stock of aluminum and copper in these systems is found to be in hibernation. The findings also indicate that cables have been disconnected to a larger extent than pipes. As an example, cables for DC power, taken out of use in the late 1930s yet still in the ground, consist of 230 tonnes of copper. The results illustrate a clear tendency for larger stocks of hibernating copper and aluminum to be found in the central rather than the outer parts of the city. A reverse, ring-like pattern is true for iron, mostly because the central parts of the town gas pipes are used for fiber optics.

Particular focus has been placed on the industrial area of Södra Butängen, which is slated for redevelopment and re-zoning from industrial to residential. Since the ground will be dug up for sanitation purposes anyway, the entire metal stock can be taken into prospecting consideration. Analysis shows that the chances of finding aluminum here are 28 times higher than in the rest of the city.

We argue for an increased MFA focus on the heterogeneous complexity found in the details of the specific locale, rather than striving for generalized assumptions about the broader picture. In doing so, MFA could very well provide a tool for a future business line of urban mining of hibernating metal stocks.

Keywords: urban mining, hibernation, infrastructure cold spots, GIS, metal stocks

1. Introduction

As capital that is literally embedded within the urban fabric, infrasystems¹ such as telecommunication and water supply make up a considerable portion of the material and economic aspects of cities. They represent long-term accumulations of finance as well as technology (Graham, 2000). Together with the building stock, infrasystems have played an important role in the unprecedented material transfer process from nature to society, which accelerated with the early stages of 19th-century modernization. At first, these infrasystems and their connecting landmarks were present in the urban landscape as iconic embodiments of a practice of progress. At a later stage, however, they were buried underground, rendered mundane and subjugated to a subterranean urban world of pipes, cables and tubes (Kaika and Swyngedouw, 2000). Some therefore argue that a late characteristic of infrasystems is that they only become visible upon breakdown (Star, 1999; Mau, 2004).

Starting with Thomas Hughes' epochal *Networks of Power: Electrification of Western Society, 1880-1930* (1983), many researchers have studied the historical growth and progress of infrasystems (e.g., Kaijser, 1994; MacKenzie, 1996; Latour and Hermant, 1998). Among these researchers a set of characteristic phases of system development has been defined: invention, development, innovation, transfer and consolidation, by following the "extend-and-supply" logic of infrastructure planning (Moss, 2008). In comparison, relatively little knowledge has been produced on the dynamics of infrastructure decline (Gandy, 2005), or the waste production of such systems for that matter. On a city level, Moss (2003) has however refined the concept of infrastructure "cold spots" first suggested by Guy et al. (1997) as "zones of limited commercial opportunity" from a system flow perspective. In a study on Berlin, Moss characterizes how extreme forms of system flow "cold spots" are created when urban sites lose their industrial function due to economic restructuring. The resulting underutilization has made infrastructure providers increasingly interested in brownfield re-development as a means to restore the loss in demand (Moss, 2008), and studies on the national German level have been conducted as well (Högselius, 2007).

Within the research field of industrial ecology there is also a tradition of studying large technical systems, primarily in order to specify the material flows related to human activities (e.g., Binder et al., 2009; Mao and

¹ The terminology used in this paper was first defined by Swedish historian of technology Kaijser (1994, pp.15-16). The infrastructure of a city or society shall be understood as the sum of all its infrasystems.

Graedel, 2009). Initially, emphasis was often on identifying sources of environmental pollution (e.g., van der Voet et al., 2000; Bergbäck et al., 2001; Lindqvist and Eklund, 2002). However, it was soon recognized that accumulations of valuable materials such as metals may also constitute important reservoirs for recovery and an approach referred to as urban mining (Brunner and Rechberger, 2004; Wittmer and Lichtensteiger, 2007; Klingmair and Fellner, 2010). So far, research related to urban mining has mainly focused on long-term potential for conservation through increased recycling rates as the employed metal stocks successively turn into waste (van Beers and Graedel, 2003; Kapur and Graedel, 2006). In-use stocks of copper have for example been reported (Spatari et al., 2005; Daigo et al., 2009), and a few papers have had a spatial component in the analysis as well (Kapur and Graedel, 2006; van Beers and Graedel, 2007).

Almost a decade ago, several studies concluded that some of the employed metal stocks have been taken out of use over time without being collected into the societal waste streams (Hedbrant, 2003). Such accumulations of obsolete metal, still remaining in their original, often urban locations, have been termed hibernating stocks (Bergbäck and Lohm, 1997; Brunner and Rechberger, 2004; Hashimoto et al., 2007).

Due to the size of the agglomerated metal quantities, cities appear to be a natural starting point when prospecting for secondary resources (cf., UNEP, 2010). There are also a few studies that have quantified in-use metal stocks in such urban environments (van Beers and Graedel, 2003; Recalde et al., 2008). However, there is still a general lack of knowledge regarding the occurrence of hibernating stocks (Kapur and Graedel, 2006), since most Material Flow Analysis studies stop at the assumption that the difference between input and output flows is simply stocked somewhere in society (Gest and Graedel, 2008). A few exceptions however have identified a significant potential for a possible “hibernation mining” line of business (the U.S. telecom consulting firm Design Nine, 2006; Krook et al., 2011), and some quantitative assessments of hibernating stocks of steel have been conducted (Daigo et al., 2007).

1.1. Aim

With the overall aim of analyzing the potential for urban mining, this study quantifies and spatially localizes metal stocks of copper, aluminum and iron (including steel) in infrasystems in the city of Norrköping, Sweden. The key concern is the hibernating metal stock of Norrköping's underground infrastructure. This stock consists of whole, inactive infrasystems still left in the ground and the disconnected pipes and wires of active infrasystems, which are scattered all over the urban area. Due to the

presumably large size of this currently obsolete granulate, we suppose a major potential for material recovery. In saying that, we assess how system flow “cold spots” could indeed be seen as “hot spots” from an urban mining/material flow perspective. Of special interest is the industrial area Södra Butängen, which is slated for re-development and thus considered a potential metal recovery “hot spot” since the ground will be dug up during the development process for sanitation purposes.

2. Conceptual framework

The quantities and spatial distribution of metal stocks are a crucial parameter when trying to define the potential for realization of urban mining. The conceptual framework for this paper is that extraction of metals from the hibernating stock is comparable to conventional mining, where the McKelvey resource classification system is conceptually used to classify and distinguish what are referred to as reserves from other resources (Fig.1). Using the terms from the McKelvey system, hibernating stocks of metals in infrastructure constitute a possible resource, with critical uncertainties both in terms of economic feasibility and lack of knowledge of stock location. Just like in conventional mining where prospecting methods are used to enlarge the reserve stock, similar prospecting in terms of urban mining studies aims to increase the level of certainty concerning the stocks of interest.

Fig. 1. The McKelvey resource classification system is the conceptual framework of the paper. Prospecting for hibernating metal stocks in urban underground infrasystems target an increased degree of certainty about the potentially recoverable resources, from undiscovered to probable as indicated by the arrow in the diagram. Figure based on Smil (2003).

In this paper, we increase the degree of certainty by localizing and quantifying hibernating infrastructure stocks and thus conceptually move them from possible into probable resources. The economic feasibility of recovery of metal stocks in the infrastructure, a movement along the y-axis in the McKelvey classification system, is not further discussed in this paper (Fig. 1). The overall method for data collection of this paper is a static or bottom-up approach of Material Flow Analysis (MFA) (cf., Kapur and Graedel, 2006). This means that instead of considering material flows in and out from the studied system, the material content is directly quantified and spatially assessed. The quantification is performed for the stocks of copper, aluminum and iron (including steel) e the three metals dominating urban infrastructure in tonnes of materials (UNEP, 2010).

3. Norrköping's infrasystemic history and the planned industrial renewal of Södra Butängen

Since every city has a different infrastructure configuration, we believe it is important to highlight historical particularities to understand the specificity of a particular urban mine. Norrköping is located in east central Sweden and has about 84,000 people in its metropolitan area (Statistics Sweden, 2011). During the early industrialization of the 1850s and on, Norrköping became Sweden's first major industrial city and at the turn of the 20th century was referred to as the Manchester of Sweden due to its prosperous textile manufacturing. Most of the cotton factories were shut down during the course of the 20th century but are still a visible cultural heritage in the city center, where one of Sweden's two large-scale operating tramlines frequently passes on what is the nation's oldest street grid (Horgby, 1989). Norrköping was also Sweden's second city to get its own gasworks in 1851. The city was electrified with DC power from the late 1870s, which was later followed by a transition to the present-day AC power system (Kaijser, 1986). Ever since Norrköping was connected to the national Swedish trunk railway in 1866, the train station and adjacent track field have been a barrier to any extension of the city center towards the north. For Butängen, as this northern part is called, this has meant a history of low land prices and a good location for industrial activities such as car garages, welding companies and small-scale manufacturing. The southern part of this area, Södra Butängen, was targeted in 2002 by the municipality of Norrköping as a development possibility, which later materialized into plans to redevelop the entire site into a sustainable city block and in the process demolish all existing buildings (Norrköping Municipality, 2009). When this eventually happens, we believe it to be a window of opportunity for urban mining. To be able to make spatial comparisons, Södra Butängen constitutes approximately 2% (0.6 km²) of Norrköping's urban area.

4. Method

The infrasystems involved in this study were chosen based on assumed size and metal content, and both cable- and pipe-based systems were considered of interest. Entirely inactive infrasystems as well as active ones, where disconnected parts constitute the hibernating metal stock, were assessed.

In comparison to many other countries, Swedish infrasystems are to a larger extent buried underground for security of supply purposes (Energy Markets Inspectorate, 2011). Since airborne and surface cables and pipes seldom remain in their spatial location after being taken out of practice (Krook et al., 2011), the study was delimited to underground infrasystems. Based on these criteria, the following five major types of infrasystems were selected: AC power; DC power; telecommunication, town gas and district heating (Table 1). Water and sewage as well as smaller active infrasystems for electricity distribution such as traffic signals have been ruled out because of a presumably low degree of hibernating metals (Englund, 2010; Lundmark, 2011). Furthermore, the study is limited to pipes and cables while, for example, street transformers and manholes have not been taken into account, although these entities can contain significant stocks of metal (van Beers and Graedel, 2007).

Table 1. Characteristics of the selected infrasystems in the urban area of Norrköping. Major type of data sources [A] GIS information; [B] Digitalised maps; [C] Statistics from operators, and [D] Statistics from historical sources, rounded numbers.

Characteristics	Cable Networks				Pipe Networks		
	AC Power		DC Power		Telecom	Town gas	District Heating
Subsystems	Grid	Private Cables	Grid	Tram Lines	-	-	-
Infrasystem state	<i>Active</i>	<i>Active</i>	<i>Inactive</i>	<i>Active</i>	<i>Active</i>	<i>Inactive</i>	<i>Active</i>
Metal of interest	Aluminum (Al) Copper (Cu)	Aluminum (Al) Copper (Cu)	Copper (Cu)	Copper (Cu)	Copper (Cu)	Iron (Fe)	Iron (Fe)
Main method for data collection	[A][B][C]	[A][C]	[B][D]	[B][C]	[B][C]	[B][D]	[A][C]
Total system length (m)	1 280 000 ^a	55 200 ^c	230 000 ^d	16 600 ^e	n/a	129 000 ^g	400 800 ⁱ
Total length in hibernation (m)	n/a ^b	13 200 ^c	230 000 ^d	12 400 ^f	n/a	104 000 ^h	26 300 ⁱ

^{a)} E.ON el (2011); ^{b)} weight estimation only, see text for detail; ^{c)} GIS data, Norrköping (2011); ^{d)} Norrköping (1938-1985) ^{e)} Statistics from former operators ^{f)} Digitalized map (Lundmark, 2011); ^{g)} Ekdahl (1951) and Norrköping (1938-1985); ^{h)} Sahlin (2010); ⁱ⁾ E.ON värme (2011);

4.1. Quantification and spatial allocation

A set of different spatial allocation methods were developed to arrive at hibernating stock estimates, combining the metal content with corresponding spatial information. The key parameter for all involved infrasystems was the metal content per meter of cable or pipe, which was multiplied by a length factor to achieve both the active and inactive stock for the metals concerned. In some cases, the reverse has also been used, distributing a known total weight to a known total length of hibernating stock. Since a city is made up of a multitude of city districts and building typologies, the spatial distribution of the inactive stock has been acquired for all infrasystems to be able to show metal concentration gradients for 36 different urban districts. The GIS software used was MapInfo Professional 10.5 and the data encompass four types of sources: GIS information, digitalized maps, data from operators, and former operator statistics. The active stock has only been considered in total numbers, in part due to the sensitive character of the spatial distribution of this data.

4.2. The infrasystems of Norrköping

An infrasystem for AC Power currently supplies Norrköping with electricity. This extensive system is operated by the German power supplier E.ON, who provided us with data regarding its total length and composition (E.ON El Norrköping, 2011). The total active weight was calculated based on the concentrations of copper and aluminum for different voltage spans (EBR, 2009), while for the hibernating metal stock the exact conductor areas were known and multiplied by the length for each disconnected cable. Although E.ON does not keep track of its inactive grid in its GIS software, we were able to receive 180 image files of maps for five of the 36 city districts and digitalized every inactive cable shown in these maps manually. Furthermore, all five of these districts were chosen for their particular characteristics: an older single-family housing area, a newer single-family housing area, a multifamily housing area, an industrial area, and the city center, which we were informed by one of our respondents was literally “stuffed with cables” (Johansson, 2011). Based on the building types of these areas and three different age intervals when considering family houses, we arrived at estimates of metal concentrations per housing unit, which were distributed overall the 10,903 buildings in the urban area of Norrköping. Allotment gardens, carports and outhouses were considered to contain no hibernating stocks.

Private actors must apply for special permission to lay down AC Power cable in areas owned by the public authorities and such cables are virtually always left in the ground when companies move, go bankrupt or shut down

their activity for some other reason. The technical administration unit of Norrköping had just finished a GIS project digitalizing private AC power cables and their data could therefore readily be used (Adolfsson, 2011; Sköld, 2011). The active and inactive metal stocks were calculated by combining this data with information about the copper and aluminum concentrations of the different cable types (EBR, 2009).

The first infrasystem to supply Norrköping with electricity was a DC power grid. It was used mainly for households but also took over street lighting from the town gas infrasystem (Kaijser, 1986). The entire system is inactive and left hibernating in the ground (Lundmark, 2011). For the stock size calculations, the length and copper content was considered for all four different cable types represented in the infrasystem: feeder and distribution cables as well as service and ground wire (Rasmusson, 2011). The spatial distribution was assumed to be equal to the corresponding size of the city when the DC power grid was at its longest in 1938 (Norrköping city archive).

The operating trams in Norrköping still run on DC power and had a supporting infrasystem replaced in its entirety due to malfunctioning (Lundmark, 2011). A map of these disconnected DC power cables was digitalized manually, and the lengths acquired were multiplied by template values for copper concentration, retrieved from the operator.

Town gas was Norrköping's first infrasystem and remained in use for stoves and heating until 1987 (Carlsson, 2011). Since then, it has been taken over by the Swedish telecom operator Tele2 and reused for inner-city fiber optics in 25,000 of its entire 129,000 m of pipes (Sahlin, 2010). This central part has thus not been considered part of the hibernating stock. The tubes and pipes consist of cast iron and steel (Carlsson, 2011), for which metal concentrations have been calculated based on the inner diameter and pipe thickness (Andersson and Pettersson, 2011; Ekdahl, 1951). The spatial distribution was derived from a map showing the infrasystem at its longest in 1972 (Norrköping city archive).

The first district heating pipes in Norrköping were laid in the early 1950s and the infrasystem is still expanding (Norrköping, 1938-1985; E.ON, 2011). It is currently operated by the German power supplier E.ON. The infrasystem pipes involve varying dimensions and are mainly made of steel, but since 1972 to some extent also of copper. Because age is the main reason behind disconnected district heating pipes, the hibernating copper share was expected to be negligible and has thus not been included in this study (Bocian and Sjögren, 2010). Based on a review of the operator's GIS

data, the active and inactive iron stocks were calculated taking the variations in pipe diameters, thicknesses and types into account.

All telecom cables in Norrköping's urban area that have copper conductors are operated by Skanova, a subsidiary of the government-owned telecom supplier TeliaSonera (Skanova, 2011). Even though the occupancy of this infrasystem has changed over time due to a shift in technology to fiber optics, these urban telecom cables are seldom hibernating. A reason for this is that the cables are used for various alarm systems and DSL services (Schillerström, 2011). Due to this and since the total infrasystem length is not comprehensively documented, it was only possible to calculate the in-use stock of copper for Södra Butängen.

4.3. City districts

In all, 36 urban subareas of Norrköping were identified based on the official city districts. For all infrasystems the hibernating stocks were allocated based on GIS data and the districts are thus represented with metal concentrations in the thematic maps shown in the result section.

The underlying GIS layers for these maps contain linear objects (cables and pipes) for all infrasystems except AC power, which is based on polygon objects (buildings). It should be noted that neither the GIS data nor the digitalized maps can be assumed to be complete. A partial explanation for this is that the GIS application was introduced in the daily operation after parts of the infrasystem were taken out of use (Krook et al., 2011).

5. In-use and hibernating metal stocks in the infrasystems of Norrköping

In total, the hibernating stock in the underground infrastructure of Norrköping amounts to about 5000 tonnes of metals. This is slightly above one quarter of the total in-use stock of metals present in the infrasystems covered in the study (Table 2). Since pipes are significantly heavier than cables, iron (including steel) constitutes the largest hibernating stock, with the inactive town gas infrasystem accounting for 80% and district heating the other 20%. Altogether, the AC power and DC power grids in Norrköping contain 2600 tonnes of copper, of which 560 tonnes are in hibernation. This stock of copper is thus potentially available for urban mining, and interestingly enough almost equally divided between disconnected parts of the active AC power grid (belonging to E.ON) and the inactive private AC cables and DC infrasystems, which are the responsibility of the municipality. The (non-)incentive to engage in urban mining of copper is thus equally shared between the two major infrasystem operators in the city.

Table 2. Total in-use and hibernating stocks of aluminum (Al), copper (Cu) and iron (Fe) in the studied city infrasystems of Norrköping, in tonnes. The ratio between in-use and hibernating metal stocks is also presented.

Infrasystem	Owner	Metal	In-use (tonnes)	Hibernation (tonnes)	Share in hibernation of total (%)
AC Power Grid	E.ON	Al	1210	25	<5
		Cu	2000	250	10
AC Power Private Cables	The City	Al	6	2	25
		Cu	75	45	40
DC Power Grid	The City	Cu	0	230	100
DC Power Tramlines	The City	Cu	4	35	100
Telecom	Skanova	Cu	n/a	n/a	n/a
Town Gas	Tele2	Fe	(975) ^{a)}	3560	80
District Heating	E.ON	Fe	10650	895	10

^{a)} The pipes have been partly reused as cable channels to hold cable TV cables, and later on also optical fibers (Sahlin, 2010 pers.com).

The aggregated ratios of hibernating stocks in comparison with the totals are about the same for iron (22%) and copper (21%), but for aluminum the total share in hibernation is less than 1%. A general conclusion is also that cables are more likely to get disconnected than pipes in active infrasystems.

5.1. Spatial distribution and concentrations of hibernating metals

A general pattern for all hibernating metals in Norrköping is centrality (Maps 1–3). Were it not for the fiber optics in the town gas infrasystem, iron would have been as relatively present in the hibernating inner-city stock as is both copper and aluminum. Instead, an outer city district contains the largest hibernating iron stock. If we had accounted for cast iron and steel separately and considered that the fiber optics parts are mainly laid in cast iron pipes, the hibernating steel and cast iron stocks would have been very similar in size. It is therefore likely that the hibernating stocks of the seven city districts, forming an “iron ring” around the city center, have the highest hibernating steel concentrations in the city (Map 1).

Map 1. Spatial distribution of the hibernating stock of iron in Norrköping. The infrasystems for town gas and district heating are represented here.

Being the youngest infrasystem in Norrköping, the majority of district heating pipes have far from reached their service lifespan, and consequently they contribute little to the total hibernating amount of iron. A differing case in point is the city district furthest southeast to which the town gas system never reached and thus the entire amount of hibernating iron comes from the district heating pipes (127 tonnes). We believe the cause of this to be the large-scale re-development of this area in the early 2000s.

Even more so than for iron, there is a clear tendency of centrality when looking at the spatial distribution of hibernating copper and aluminum in Norrköping (Map 2 and 3). This picture is also confirmed by the technical administration of the city (Sunnerberg, 2011), who explain that due to a general lack of space, there are relatively few street transformers in this

area. This means that the density of the grid, and thereby also the probability for disconnected cables, increases even further. It is important to remember that neither of the inactive DC systems, contributing a significant amount of hibernating copper, reached the outer parts of the city.

Map 2. Spatial distribution of the hibernating stock of copper in Norrköping. The infrasystems for AC and DC power are represented here.

Map 3. Spatial distribution of the hibernating stock of aluminum in Norrköping. The infrasystems for AC and DC power are represented here.

Following from the method used to allocate the hibernating parts of the AC power grid, the building stock within a city district seems to partially influence the size of the hibernating stock. This is because different types of buildings have largely different needs for voltage levels. In industrial or multifamily housing areas, the conductor gauges are thus substantially

larger than in grids situated in single-family housing districts, meaning that a smaller amount of disconnected cables are required to reach the same size of hibernating stock (Table 3). It is also worth noting here that aluminum conductors were first introduced in Sweden around the 1970s and have since then successively become more common. Today, aluminum conductors are the first choice even for service cables in Norrköping (Sunnerberg, 2011). So, the considerably smaller amount of hibernating aluminum than copper might be explained by the fact that such parts of the grid are often not yet old enough to contain substantial amounts of disconnected cables. Any specific occasion in the city (e.g., re-development or refurbishment projects, road construction work and exchange of street transformers) could however quickly rule out such a generalized pattern, which in turn might be a reason why some districts still have fairly large stocks of hibernating aluminum.

Time is presumably a general parameter influencing both the size and metal composition of hibernating power grids. First of all, it appears as if old city areas often contain more disconnected cables than newer parts of the grid, which is for example apparent for the city center, the oldest part of Norrköping. Such tendencies could however also be seen when comparing the amount of hibernating copper per building unit in similar types of city districts of different age (Table 3).

Table 3. Average amount of hibernating copper and aluminum with respect to building type, in kg/building unit. The data is based on the specific results for the five selected city districts. For the methodology used, see 4.2.

Building type	Single family houses			Multi-family housing	Inner-city houses	Industrial buildings	Special buildings (hospitals, churches, transformers etc.)	Other
	1945	1946-1978	1979-					
Year	-	-	-	-	-	-	-	-
Aluminum (Al)	0.8	0.9	0.9	1.2	17.4	3.5	1.9	1.6
Copper (Cu)	15.3	9.1	0.9	20.8	135.5	55.0	26.8	23.2

5.2. The case of industrial renewal in Södra Butängen: parts and the whole

The area of Södra Butängen is slated for renewal and will be rezoned from industrial to residential (Map 4). The infrastructure adjustments needed to fit the new development imply that the present stocks of metals are to a large extent likely to end up in hibernation. Consequently, the area becomes of interest from an urban mining perspective.

When Södra Butängen is renewed, the totally available metal stocks in the area will be 307 tonnes, divided between iron (248 tonnes), copper (51 tonnes) and aluminum (8 tonnes). Similar to the results for the whole urban area of Norrköping, AC and DC power infrasystems hold the largest stocks of copper, while iron is mainly found in the infrasystem for town gas. While Södra Butängen only represents 2% of the total size of Norrköping, the stocks in Södra Butängen represent a significant share of the available metal resources for urban mining in the city of Norrköping: 30% of the aluminum, 10% of the copper and 5% of the iron total stocks in hibernation (cf., Table 2).

Map 4. The industrial area of Södra Butängen facing re-development into a sustainable city block.

To be able to determine the quality of the material flow “hot spot” of an area such as Södra Butängen, it is also useful to consider metal concentrations per area unit. Taken together, the concentration (kg/m²) of available aluminum, copper and iron is significantly higher for Södra Butängen compared to the hibernating stocks in Norrköping as a whole. There is nearly 28 times as much aluminum per area unit in Södra Butängen compared with the average concentration for the entire urban area, and you are as likely to find aluminum here as you are to find hibernating copper in the rest of the city. For iron, the chances are around three times higher of finding an available “ore” in Södra Butängen than in the rest of the city.

Taken together, these findings show that re-development sites are indeed hot spots for urban mining, especially in comparison with the dispersed hibernating metal concentrations in the city. We believe that infrasystem operators might do well to consider the recycling benefit of urban mining as a secondary alternative to promoting re-development, which has been highlighted as common by other authors (Moss, 2003, 2008).

6. Concluding discussion

Although cities appear to be the main location for a large portion of hibernating stocks of metal in infrastructures, such an environment also adds extraordinary challenges regarding the conditions for recovery (Krook et al., 2011). The revenues that could be obtained for recovered metals therefore often do not even come close to outweighing the extraction costs, which is one of several reasons why infrastructure managers seldom recover their disconnected parts. This study pinpoints the importance of integrating urban mining with other urban activities and in so doing facilitating resource sharing among different actors and projects. An opportunity for such collaboration and potential synergies is the kind of industrial renewal project described in this study, where we suggest that infrastructure “cold spots” provide significant urban ores available for exploitation. The study furthermore suggests continued research on how hibernating stocks of metal occur in the urban environment. From a Large Technical Systems perspective, hibernation could for example be suggested as an infrastructure development phase.

It should be remembered that this article says nothing about the quality of the metals left underground. Although this is believed to be an exception to the rule, the state of the town gas iron pipes in Södra Butängen was described by one informant as “hard tack” since it is the old bottom of a lake (Carlsson, 2011). On the other hand, telecom cables easily last for a hundred years, assuming that no one digs through them (Schillerström, 2011).

There is furthermore reason to believe that the specific infrastructure characteristics of Norrköping significantly affect the outcome of this study, and perhaps especially the tendency of centrality seen in the hibernating copper and aluminum stocks. The share of centrally located inactive private AC cables is for example likely to be higher in Norrköping than in other Swedish cities, due to the city’s central and very apparent industrial past. Second, Norrköping has one of Sweden’s two large-scale operating tramlines, which go through the city core and thus also increase the amount of inactive DC-power lines. A factor worth mentioning which on the other hand decreases the hibernating stock is Norrköping’s old street grid, which has caused no major realignment of any of the involved infrasystems. This is because the inner-city streetscape (underneath which infrasystems generally are located) has not been altered since it was first laid out.

Although many comparative studies are needed to affirm the above outlined assumptions, there is reason to believe that cities are too unique in terms of infrastructure for any result to be generalized in terms of hibernating kilos per inhabitant or area unit. We do however still suggest

that other researchers apply the GIS-based MFA method performed in this article, if only to gain a significantly increased degree of certainty for secondary resource recovery from metal stocks in the urban infrastructure. Away forward would furthermore be to triangulate the results by performing a streetscape laser scanning or some other urban archaeology method, to help overcome inherent insufficiencies in map-based data on underground infrastructure (Boukhelifa and Duke, 2008; Huler, 2010 p. 216). Due to these, there is reason to believe our results to be underestimations. In the end, actual digging for these hibernating stocks seems crucial to go from “probable” to “proved” according to the McKelvey resource classification system (Fig. 1).

To sum up, and borrow some words from the language of the philosopher Chunglin Kwa (quoted in Law, 2003), we believe that there is a great potential to be gained for the MFA research community to further explore what he calls “a baroque sense of complexity”. This implies looking down to the heterogeneous complexity found in the details of the specific locale, rather than up at the abstract interconnectedness of the broader picture, which is typical for a romantic sense of complexity. To further develop the methodology in this article as a prospecting tool for urban mining, a baroque turn is absolutely central and a great task for future researchers to engage in

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References

- Adolfsson, M., 2011. GIS Engineer at Norrköping Municipality. Personal communication.
- Andersson, S., Pettersson, J., 2011. Potential for Urban Mining in Norrköping A Static Quantification of Metal in Subterranean Infrsystems. LiU-Tema/MC-C-11/11-SE.
- Bergbäck, B., Lohm, U., 1997. Metals in society. In: Brune, D., Chapman, D.V., Gwynne, M.D., Pacyna, J.M. (Eds.), *The Global Environment – Science, Technology and Management*. Scandinavian Science Publisher, Wiley – VCH.
- Bergbäck, B., Johansson, K., Mohlander, U., 2001. Urban metal flows – a case study of Stockholm. *Water, Air and Soil Pollution: Focus* 1, 3–24.
- Binder, C.R., Van Der Voet, E., Rosselot, K.S., 2009. Implementing the results of material flow analysis. *Journal of Industrial Ecology* 13, 643–649.
- Bocian, D., Sjögren, M., 2010. GIS Engineers at E.ON. Personal communication.
- Boukhelifa, N., Duke, D.J., 2008. The aesthetics of the underworld. In: Brown, P., Cunningham, W., Interrante, V., McCormack, J. (Eds.), *Computational Aesthetics in Graphics, Visualization, and Imaging. International Symposium on Computational Aesthetics in Graphics, Visualization, and Imaging*, June 18–20 2008, Lisbon, Portugal. Eurographics, pp. 41–48.
- Brunner, B., Rechberger, H., 2004. *Practical Handbook of Material Flow Analysis*. CR/Lewis, Boca Raton.
- Carlsson, L., 2011. Former Chief Engineer at Norrköping Town Gas Plant. Personal communication.
- Daigo, I., Igarashi, Y., Matsuno, Y., Adachi, Y., 2007. Accounting for steel stock in Japan. *ISIJ International* 47 (7), 1065–1069.
- Daigo, I., Hashimoto, S., Matsuno, Y., Adachi, Y., 2009. Material stock and flow accounting for copper and copper-based alloys in Japan. *Resources, Conservation & Recycling* 53, 208–217.
- Design Nine (US telecom consulting firm), 2006. World's Largest Copper Reserve is in the U.S. <http://www.designnine.com/news/content/worlds-largest-copperreserve-us>.
- EBR, 2009. Hantering av uttjänta kabel. Swedenergy AB (in Swedish).

Ekdahl, D., 1951. Norrköping gasverk 1851e1951: En hundraårskrönika: Kort översikt över verksamheten under ett sekel. Gasverket, Norrköping (in Swedish).

Englund, P., 2010. GIS Engineer at Norrköping Vatten. Personal communication.

E.ON El Norrköping, 2011. www.eon.com.

E.ON Värme Norrköping, 2010. www.eon.com.

Energy Markets Inspectorate, 2011.

www.energimarknadsinspektionen.se/Energy-Markets-Inspectorate/.

Gandy, M., 2005. Cyborg urbanization: complexity and monstrosity in the contemporary city. *International Journal of Urban and Regional Research* 29, 26–49.

Gest, M.D., Graedel, T.E., 2008. In-use stocks of metals: status and implications. *Environmental Science and Technology* 42, 7038–7045.

Graham, S., 2000. Introduction: cities and infrastructure networks. *International Journal of Urban and Regional Research* 24.1, 114–119.

Guy, S., Graham, S., Marvin, S., 1997. Splintering networks: cities and technical networks in 1990s Britain. *Urban Studies* 34 (2), 191–216.

Hashimoto, S., Tanikawa, H., Moriguchi, Y., 2007. Where will large amounts of materials accumulated within the economy go? e a material flow analysis of construction minerals for Japan. *Waste Management* 27 (12), 1725–1738.

Hedbrant, J., 2003. Structuring Empirical Knowledge on Environmental Issues. Urban Heavy Metal Metabolism. PhD thesis. Linköping Studies in Arts and Science 283. Linköping, Sweden.

Högselius, P., 2007. Postmodern Power: The Cultural Shift in Electricity System–Building at the Turn of the Millennium. Paper presented at the joint Tensions of Europe and Inventing Europe Conference, Rotterdam, 7–10 June 2007.

<http://perhogselius.files.wordpress.com/2010/09/postmodern-power-7-10-june-20071.pdf>.

Horgby, B., 1989. Surbullestan. Carlsson, Stockholm (in Swedish).

Hughes, T., 1983. Networks of Power. Johns Hopkins University Press, London.

- Huler, S., 2010. *On the Grid*. Rodale Books, New York.
- Johansson, H., 2011. Engineer at E.ON. Personal communication.
- Kaijser, A., 1986. *Stadens ljus: etableringen av de första svenska gasverken*. Liber Förlag, Malmö (in Swedish).
- Kaijser, A., 1994. *I fädrens spår: den svenska infrastrukturens historiska utveckling och framtida utmaningar*. Carlsson, Stockholm (in Swedish).
- Kaika, M., Swyngedouw, E., 2000. Fetishizing the modern city: the phantasmagoria of urban technological networks. *International Journal of Urban and Regional Research* 24.1, 120–138.
- Kapur, A., Graedel, T.E., 2006. Copper mines above and below the ground. *Environmental Science & Technology* 40, 3135–3141.
- Klingmair, M., Fellner, J., 2010. Urban Mining in times of raw material shortage copper management in Austria during World War I. *Journal of Industrial Ecology* 14 (4), 666–679.
- Krook, J., Carlsson, A., Eklund, M., Frändegård, P., Svensson, N., 2011. Urban mining – hibernating copper stocks in local power grids. *Journal of Cleaner Production* 19 (9–10), 1052–1056.
- Latour, B., Hermant, E., 1998. *Paris ville invisible. Les Empêcheurs de Penser en Rond/La Découverte*, Paris (in French).
- Law, J., 2003. *And if the Global Were Small and Non-Coherent? Method, Complexity and the Baroque*. Center for Science Studies, Lancaster. <http://www.lancs.ac.uk/fass/sociology/papers/law-and-if-the-global-were-small.pdf>.
- Lindqvist, A., Eklund, M., 2002. A regional cadmium inventory: interpretation and management. *Local Environment* 7 (3), 295–310.
- Lundmark, P., 2011. Electricity Engineer, Norrköping. Personal communication.
- MacKenzie, D., 1996. *Knowing Machines: Essays on Technical Change*. The MIT Press, Cambridge.
- Mao, J., Graedel, T.E., 2009. Lead in-use stock. A dynamic analysis. *Journal of Industrial Ecology* 13 (1), 112–126.
- Mau, B., 2004. *Massive Change*. Phaidon, London.

Moss, T., 2003. Utilities, land-use change, and urban development: brownfield sites as 'cold spots' of infrastructure networks in Berlin. *Environment and Planning A* 35, 511–529.

Moss, T., 2008. 'Cold spots' of urban infrastructure: 'shrinking' processes in eastern Germany and the modern infrastructural ideal. *International Journal of Urban and Regional Research* 32 (2), 436–451.

Norrköping, 1938. Statistical Yearbook of Norrköping. Norrköping City Archive.

www.norrkoping.se/organisation/kommunen/kommunstyrelsen/kskontor/kommunservice/stadsarkiv/. Norrköping City Archive, Kartsamlingen. J6a Anläggningar, Vol. 38 U år 1.

Norrköping municipality, 2009. Comprehensive Plan for Södra Butängen. City of Norrköping, Sweden.

Rasmusson, B., 2011. Expert on Power Cables, Sony Ericsson. Personal communication.

Recalde, K., Wang, J., Graedel, T.E., 2008. Aluminum in-use stocks in the state of Connecticut. *Resources, Conservation and Recycling* 52, 1271–1282.

Sahlin, T., 2010. Planner Tele2, Norrköping. Personal communication.

Schillerström, M., 2011. Cable Planner, Skanova, Sweden. Personal communication.

Skanova, 2011. www.skanova.se.

Sköld, B., 2011. Archive assistant, Norrköping Municipality. Personal communication.

Smil, V., 2003. Energy at the crossroads: global perspectives and uncertainties. Massachusetts Institute of Technology. USA, citing McKelevey, V.E., 1973. In: Btrobst, D.A., Pratt, W.P. (Eds.), *Mineral Resources Estimates and Public Policy*.

United States Mineral Resources. USGS, Washington, DC.

Spatari, S., Bertram, M., Gordon, R.B., Henderson, K., Graedel, T.E., 2005. Twentieth century copper stocks and flows in North America: a dynamic analysis. *Ecological Economics* 54, 37–51.

Star, S.L., 1999. The ethnography of infrastructure. *American Behavioural Scientist* 43 (3), 377–391.

Statistics Sweden, 2011. www.scb.se.

Sunnerberg, K., 2011. Engineer and Cable Consultant, E.ON, Norrköping. Personal communication.

Tanikawa, H., Hashimoto, S., 2009. Urban stock over time: spatial material stock analysis using 4d-GIS. *Building Research & Information* 37 (5-6), 483–502.

Tanikawa, H., Inazu, R., Hashimoto, S., Kaneko, S., 2008. Estimation of historical/spatial changes in subsurface material stock related to the construction sector of urban areas in Japan. *Hydrological Change and Watershed Management*, 591–597.

UNEP, 2010. Metal Stocks in Society. Scientific Synthesis Global Metals Flows Group of UNEP's International Panel for Sustainable Resource Management. United Nations Environment Programme.

van Beers, D., Graedel, T.E., 2003. The magnitude and spatial distribution of in-use copper stocks in Cape Town, South Africa. *South African Journal of Science* 99, 61–69.

van Beers, D., Graedel, T.E., 2007. Spatial characterization of multi-level in-use copper and zinc stocks in Australia. *Journal of Cleaner Production*, Special Australia and New Zealand Issue 15, 849–861.

van der Voet, E., Guinée, J.B., Udo de Haes, H.A., 2000. Heavy Metals: A Problem Solved? Methods and Models to Evaluate Policy Strategies for Heavy Metals. Kluwer Academic Publishers, Dordrecht.

Wittmer, D., Lichtensteiger, T., 2007. Development of anthropogenic raw material stocks: a retrospective approach for prospective scenarios. *Minerals & Energy* 22, 62–71.