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Focusing on

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Materials Case Study 1:

Critical Metals and Mobile Devices

Working Document

OECD Environment Directorate, OECD, 2010

NOTE FROM THE SECRETARIAT

In addition to aluminium, wood fibres and plastics, critical metals have been identified as priority materials for which sustainable management would bring significant environmental, social and economic benefits. The objective of this case study on critical metals is to analyse the environmental impacts of critical metals throughout their lifecycle and identify the best practices for their sustainable management.

This case study will be presented at the OECD Global Forum on Sustainable Materials Management to be held in Belgium from 25 to 27 October 2010 and, together with the other three case studies, will serve as a basis for the discussions of Session 1 on *Good SMM Practices in Priority Materials.*

The Government of Canada case study project team involved participants from three federal departments: Natural Resources Canada (NRCan), Industry Canada (IC) and Environment Canada (EC).

The project team was led by Alain Dubreuil and Rob Sinclair in the Minerals and Metals Sector of NRCan.

Project support was provided by Orlando Dinardo (NRCan), Philippa Huntsman-Mapila (NRCan), David Koren (NRCan), Peter Campbell (IC), Patrick Huot (IC), Cheryl Beillard (NRCan), Duncan Bury (EC), Dennis Jackson (EC) and Andre Martin (EC).

Alberto Fonseca and Steven B. Young (University of Waterloo) were sub-contracted to conduct a literature review and develop an analytical framework for advancing research into the social aspects of sustainable metals management.

Nokia, Umicore, the US National Research Council of the National Academies and many other players have provided valuable information that was used in the preparation of this case study; however, the content of this document, including any errors or omissions, shall remain the responsibility of the project team alone.

This report is work in progress. The opinions expressed in this paper are the sole responsibility of the author(s) and do not necessarily reflect those of the OECD or the governments of its member countries.

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EXECUTIVE SUMMARY

Why was this report prepared?

The Organization for Economic Cooperation and Development (OECD) has a Working Group on Waste Prevention and Recycling (WGWPR) that has been exploring the concept of Sustainable Materials Management (SMM) since 2004. This case study, being one of four, was prepared to determine whether the SMM concept is useful when considering the availability of critical metals in relation to the management of end-of-life products, specifically mobile phones which serve as proxy for the rapidly growing consumer electronics sector. Since SMM is still in its adolescence, the case study approach provides a good opportunity to identify areas for the potential application of different tools and policy instruments for government policy makers concerned with material use and the optimization of economic, environmental and social benefits.

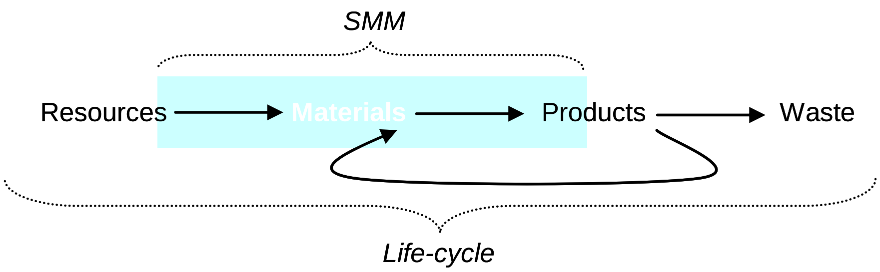
This case study relates to the metals found in mobile devices. The metals considered in this case study are antimony, beryllium, palladium and platinum. The case study is submitted to the SMM Steering Committee for their consideration and input to the October 2010 SMM workshop.

What is sustainable materials management (SMM)?

Before delving further into the heart of this case study, it would be useful to present the working definition of SMM (which is repeated and expanded upon in the Introduction as well as in other WGWPR papers).

SMM is "an approach to promote sustainable materials use, integrating actions targeted at reducing negative environmental impacts and preserving natural capital throughout the life cycle of materials, taking into account economic efficiency and social equity." Accordingly, sustainable development (SD) is the overarching goal and SMM is the means to get there, by embracing policy integration, life cycle thinking, efficiency and equity in developing and assessing policies to promote the sustainable use of materials.

The conundrum that arises with SMM is that policy initiatives to optimise the sustainable use of materials are linked to different "points" across the life cycle: as illustrated in the following graphic, where does SMM begin and end.



How was the work done?

The draft programme of work and the budget for 2009-10 for the WGWPR article 7 provides clear terms of reference for this project: "*The case studies would be built on existing data on material flow in the selected areas*." In other words, though this case study may identify important data gaps, no primary research would be conducted to bridge them. If deemed important, further work could be undertaken under the auspices of the OECD/WGWPR. The composition of the Government of Canada project team is provided under Acknowledgements, which follows the Table of Contents.

Who is the report for?

The primary audience for the SMM case study work is government policy makers, industry leaders and civil society members. In some OECD countries, responsibilities for recycling and related matters are shared or divided between two or even three levels of government. A response to this question might be that SMM is in search of material management solutions further up the product stream and this is the natural domain of national or even international agents that may have more influence over such matters than cities and towns. Therefore this report is for policy makers interested in joining the discussion on the merits of SMM.

What are the key policy points in the report?

General

- The benefits and costs of mobile phone use or recycling/disposal are unevenly distributed across all three sustainable development dimensions – environmental, social and economic – particularly in developing countries.
- The life cycle approach to supply chain management is extremely beneficial.
- Even if complete capture of all mobile devices and maximum recycling of the metals they contain were achieved, there would still be a need for primary mining to meet growing demand for the services metals provide.
- In the life cycle of consumer electronic devices, the design stage is of critical importance since this is where the type and quantity of materials is determined. Decisions made at this stage will have direct economic and environmental impacts when the devices are recycled.
- As with most consumer electronics, the mobile phone industry has demonstrated a tremendous capacity for rapid technological change. Specifically, the introduction of new (non-metallic, polymer based) materials may impact future reuse and recycling activities. In this regard, technological innovation is an important policy driver.

Economic

- Since the outcomes or results of SMM planning occur across three different dimensions (economic, environmental and social), it is very difficult to establish a fair and balanced way of assessing total costs and benefits.
- Many consumer electronic products retain residual reuse or material value, particularly those that contain metals; unless they are lost into the waste stream, these products are globally traded commodities; by thinking globally and acting locally, national policy makers can contribute towards a comprehensive, international approach in managing these products and their materials, as discussed in this study, to the sustainable use of the metals contained therein.

- The geographical profile of a metal greatly influences the degree of its criticality. By and large, critical metals are mined in a limited number of locations (or co-produced with base metals) though they may be found in many other places: when prices rise, mines open.
- The origin of the metal (primary or secondary) is determined by economics and availability. The economic value of a metal does not necessarily reflect or correlate with criticality (*e.g.* gold).
- Managing the flow of expired mobile phones might optimise the recovery of metals from them but could raise trade issues in certain circumstances. Policies that seek to change or control these flows may create non-tariff trade barriers.
- Alternative materials are considered during the product design stage. The potential for and the degree of material substitution links directly to issues of scarcity and pricing.
- When scarcity drives prices of primary metals up, for example, markets will recycle much more metal and invest in appropriate technology as required.

Environmental

- Material grade is determined by conformity to established specifications.
- Informed product design, economic efficiency in the use of resources and an effective recycling infrastructure are the best ways of preserving "natural capital".
- The collection of all such devices, reuse of their parts or recycling of component materials is a major contributor to maximizing resource efficiency.
- Recycling is an energy efficient activity that, in turn, reduces greenhouse gas emissions (though the benefits are material specific).
- Recycling facilities that operate under environmentally sound management standards should be able to process materials regardless of the facility location or the source of the materials. An inventory of Environmentally Sound Management (ESM) facilities around the world that have the ability to process end-of-life consumer electronics is needed, which could be proposed to the Basel Convention secretariat as a future project.
- Substitution can be used to replace toxic or non-recyclable components but adverse product quality changes are possible and must be carefully scrutinized using a risk assessment approach to avoid negative effects.

Social

- Consumers, producers and government are the primary players when it comes to sustainable management of materials and products but the first two have different perspectives and drivers than governments that are responsible for optimizing benefits and/or minimizing risk for their constituents.
- Social life cycle assessment is an emerging tool to address the social implications of sustainable materials use but more work is required to further develop the methodology for the benefit of more informed policy making.

Principle SMM questions and preliminary responses

What are the current estimated major resources flows (in terms of environmental impacts) and how are they expected to evolve?

The annual sale of mobile phones is currently around 1.2 billion units weighing 84,000 tonnes (excluding batteries). Where the metals of interest are concerned, 84 tonnes of antimony (Sb), 7.1 tonnes of beryllium (Be), 12.1 tonnes of palladium (Pd) and 0.3 tonnes of platinum (Pt) are used to make these devices. First, life cycle data for Sb and Be are currently not available. Second, material flows cannot by themselves be used as a proxy for environmental impact. Third, the question of impacts cannot be addressed without the application of additional SMM methodologies.

The number of mobile devices sold annually will continue to increase. Individual device weight will depend on innovation and consumer demand, while some manufacturers are signaling that Be and Sb content will probably be phased out due to health/toxicity concerns. Demand for Pd and Pt in other products such as pollution control devices is expected to increase, leading to higher prices for these metals; as a result, new technology using different materials is likely to be developed. However, projections regarding new devices and new material applications are extremely tenuous given the rapidity of change over recent years.

How can new insights be gained and translated into new measures when taking a life cycle perspective?

The life cycle approach provides recyclers and waste managers with the opportunity of appreciating and possibly affecting the type and volume of materials that flow in and out of the proverbial "pipe." Where mobile devices are concerned, enhanced life cycle understanding may be used to support and expand current reuse and recycling activities. In particular, the collaboration of recyclers and product designers would be an interesting way of bridging the gap that appears to exist between them: by understanding the interactions and dependencies inherent in the design, production, use, reuse and recycling life cycle stages, new measures to improve efficiencies may be identified.

What policy measures have been taken or can be taken to stimulate sustainable outcomes?

Where materials processing is concerned, recycling does save energy. Public policy should promote the link between energy savings, improved economics and reduced GHG emissions. To improve recycling yields and reduce exposure to workers, policies to manage risk include raising awareness and setting standards. Where some mobile phone material has been identified as problematic for recyclers, manufacturers are starting to phase these materials out (Be and Sb for example). Design for recycling is conceptually desirable and may be influenced by the introduction of relevant policies such as extended producer responsible (EPR) or individual producer responsible (IPR). Where domestic policy making has resulted in EPR programs, experience has shown that product capture rates usually rise. This is probably the best approach to managing end-of-life consumer products such as mobile devices. In fact, most device manufacturers or the wireless service providers offer some sort of take-back program for these products: the challenge is in getting the general public to engage. Given their diminishing life span, a deposit system for these devices or innovative leasing arrangements may be good mechanisms for raising collection rates. A national or regional ban on the disposal of these devices sends a strong message to the general public but ultimately such a regulation is unenforceable and perhaps useless if adequate recycling infrastructure is lacking. Since the technical lifespan of a mobile phone is about ten years, promoting extended mobile phone use through policy ultimately supports sustainable use of materials. Government procurement contracts could specify product durability requirements; alternatively, standard government policy could extend electrical and electronic equipment usage periods. A mix of policies and programs is likely the most effective approach. Further information regarding measures already undertaken has been assembled in a separate OECD report entitled "*Inventory of International Initiatives Related to Sustainable Materials Management*" (Sep-2008): Some of these initiatives include corporate social responsibility, integrated product policies, clean production centres, green procurement, eco-labeling and EPR (etc.).

To what extent are different actors in society engaged in active, ethically based responsibilities for sustainable outcomes?

A considerable amount of work is underway to address various issues related to consumer electronic products specifically, and metals in general. On page 36 of document "Critical Metals Case Study Annexes", Figure 3 identifies 25 different initiatives that are either international (MPPI, PACE, GeSi and StEP, etc.) or national (*e.g.* Canada, Australia) in nature. Some of the descriptor words used in the titles of these initiatives include "responsible", "stewardship", "commitment", "sustainability", "coalition" and "partnership." Questions arise concerning extent: are 25 such initiatives too few or too many? How are these programs being monitored and assessed? How well are these programs performing (re: outcomes)? Are they cost-effective? Why were they established in the first place? Are the right partners at the table? Who is funding or supporting the work? These are all good questions which remain to be addressed.

What are the primary knowledge gaps?

- The global flow of mobile phones destined for reuse or recycling is largely unknown.
- Life cycle data for some critical metals production are sparse.
- GHG and energy data assembled for this case study were aggregated at the extraction/refining and manufacturing stages: separate data sets for each stage are required.
- Can the hidden social costs underlying critical metals and mobile phones production/recycling processes be measured?
- How can the economic and social benefits of mobile communication devices be compared with the environmental and social impacts of improper disposal or recycling?
- Why do mobile phone users hoard obsolete units and what is the best way to engage the consumer in planned or already established collection programs?
- What is the average cost of mobile phone refurbishment and what is the displacement relationship between reused mobile phones and the production of new ones?
- What is the extent and size of the informal recycling sector for consumer electronic products?
- Further economic analysis is required to improve the comparison of informal (low tech) and smelter (integrated pyrometallurgical) based recycling operations.
- Further science is required to measure the risk associated with final disposal of mobile phones when they are disposed of in engineered landfills and "high-tech" incinerators with emissions control versus "low-tech" landfills and incinerators with poor or no controls.

How can the report findings be used?

The report findings are summarized under the key policy points and the primary knowledge gaps discussion that preceded this paragraph. These areas were the main focus of this case study. More detail for both can be found in Sections 4 and 5 of the main report.

In this report, four SMM methodologies (substance flow analysis, life cycle assessment, eco-efficiency, and a proposed social aspects framework) are used to document the state of knowledge concerning the source and fate of critical metals contained in mobile phones. The mobile phones should be considered as a proxy for other consumer electronic products although it is acknowledged that while their proportion in the solid waste stream is rapidly expanding in relative terms, their presence in the landfills and incinerators of the world is relatively very small, in absolute terms (less than 0.1% by weight in Canada).

Despite these small quantities, the presence of valuable metals in mobile phones, both critical and precious, has attracted significant interest. Are these metals a risk when discarded into the environment? Are these metals worth recovering? What are the opportunities and the barriers to increased recycling? These are some of the questions that policy makers could consider with a view towards building a broader understanding of how to apply SMM. Another task could involve national consultations to raise awareness among stakeholders of the concept and seek their feedback on its relevance.

Government policy makers will have different views regarding the critical nature of the metals used in consumer electronic devices. This report has indicated that the concept of criticality is subjective, geographically specific and likely to change through time. Underlying the concept is the idea of 'motive'. Drivers of criticality are primarily commercial or economic. Manufacturing nations have an interest in ensuring future supplies of metals required to produce the economic goods on which their economic and social well-being depends at a price which maintains their global competitiveness. Sudden interruptions in the supply of metals deemed 'critical' for specific applications may result in significant economic or social dislocation. Hence 'criticality' may be linked to 'availability' and demand. Where an interest or application is 'strategic', *i.e.* related to national defence, cost is rarely an issue. This paper does not attempt to address the rationale underlying the identification of 'critical metals', as it will vary by country and over time.

Some important conclusions reached in this study are as follows: First, the collection of used mobile phones needs to be greatly improved in Canada and other OECD countries. Second, the triage or sorting stage that follows collection optimizes device reuse, which is a key economic driver in sustaining these programs. Third, there may be a preference on the part of original equipment manufacturers to encourage recycling over reuse in order to support new product sales. Fourth, interim processors play an important role in which the disassembly of used mobile phones leads to parts reuse, removal of contaminants and material recovery. Fifth, facilities that are efficiently operated and achieve maximum recycling yields should be competitive enough on the world market to procure sufficient feedstock (including end-of-life mobile phones), though companies that operate with lower standards create an uneven playing field. If governments intervene to secure supplies of specific metals to manufacturing nations, that would run counter to the broader commitment of the OECD to the market economy and goal of assisting other countries' economic development. Sixth, since informal recycling in developing countries has negative environmental and health consequences, it is imperative that environmentally sound management capacity be developed because the number of mobile phone users in Asia and Africa is rising very quickly.

Policy interventions to support SMM activities such as mobile phone collection and recycling can be introduced across the life cycle of this device. The scope and depth of government intervention will vary across all OECD member states according to political agenda and "culture." In an extreme case, national governments may be able to support or even mandate design for recycling via discussions of EPR with industry; however, this is big challenge for countries without a large manufacturing base. Alternatively, discussions with Telecom companies via forums such as the Mobile Phone Partnership Initiative (MPPI) may lead to voluntary initiatives that seek to achieve the same goals (*e.g.* the removal of beryllium from mobile phones to address worker health and safety issues). Another part of the life cycle where policy intervention may have an impact is the end-of-life stage where users decide what to do with obsolescent mobile phones. For example, the redemption of a mobile phone deposit fee or a ban on disposal may result in an increased collection rate that would in turn result in increased recycling activities. A more extensive discussion of SMM policy principles and instruments is provided in the thematic papers, also being prepared for the OECD's Working Group on Waste Prevention and Recycling (WGWPR).

The selection of four critical metals found in mobile phones was undertaken to contain the analysis. On an annual volume basis the broader electronics industry uses 5% of the world's platinum, 16% of its palladium, 50% of its antimony and about 7% of its beryllium (as a beryllium copper alloy). Metal mix is product dependant and subject to constant change as technology evolves over time. The global economy will continue to place demands on available metal stocks: these demands are fluid and mostly resolved in the global marketplace. Perhaps policy makers need to consider how the SMM process might influence the marketplace in a manner that optimizes the use of scarce resources.

What are some next steps?

There is no doubt that more effort is required to improve the knowledge of end-of-life mobile phone flows. Policy makers could discuss this prospect with the wireless industry to determine if there are any viable tracking systems already in place: perhaps the only issue is consolidation of disparate information. The coordination of national tracking activities may best be left with an industry comprised of manufacturers, retailers, collection agents, refurbishers, recyclers and smelters. The mobile phone "brand owners" may be best positioned to assume this coordinating role and indeed have made important contributions towards the Basel Convention's Mobile Phone Partnership Initiative.

A better understanding of what people do with mobile phones that reach their real or perceived end of life would be worth further examination. Policy makers could conduct consumer surveys to determine why existing collection systems are not used. They should also work with the industry players identified in the previous paragraph to determine lessons learned and best practices. This is ongoing work.

Of all the instruments that fall under the SMM umbrella, the life cycle approach is arguably the most important. The life cycle approach is no longer an academic-only activity. In the business world, reference is frequently made to the triple bottom line (economic, social and environmental), which promotes sustainable development and corporate social responsibility. In the context of this case study, mobile phone manufacturers that subscribe to the triple bottom line may be engaging in SMM activities under a different name. The promotion of such companies as being "best in class" or "front runners" would be an appropriate role for national governments or international agencies to play. This is how life cycle thinking becomes common currency.

While this paper does not address the idea in detail it does suggest that a material's criticality can be influenced by the availability of alternatives. Material substitution, in turn, is impacted by various social and economic patterns as well as technological change. Where government undertakes to promote substitution based on environmental or human health concerns, policies designed to promote such shifts should be applied on a case-by-case basis, using sound science and risk assessment as well as the evaluation of the risks associated with potential alternate materials. Why and when one material is replaced by another is of interest to policy makers and perhaps represents an opportunity to exercise some of the SMM principles and policies elucidated elsewhere. It is generally understood that industry undertakes material substitution very carefully and over some time to avoid mistakes that would otherwise compromise production processes, product performance and the profit prerogative.

RÉSUMÉ

Pourquoi ce rapport ?

Au sein de l'Organisation de coopération et de développement économiques (OCDE), le Sous-groupe sur la prévention de la production de déchets et le recyclage (SGPDR) travaille depuis 2004 sur le concept de gestion durable des matières (GDM). Cette étude de cas, qui fait partie d'une série de quatre études, a été réalisée afin d'établir si le concept de GDM est utile pour examiner la disponibilité des métaux critiques dans l'optique de la gestion de produits hors d'usage, en l'occurrence les téléphones mobiles, qui servent de variable représentative du secteur en croissance rapide de l'électronique grand public. Étant donné que la GDM n'est pas encore parvenue à maturité, l'approche fondée sur les études de cas offre une bonne occasion d'identifier les domaines qui peuvent se prêter à l'application de différents outils et instruments d'action pour les responsables de l'action gouvernementale soucieux de l'utilisation des matières et de l'optimisation des avantages économiques, environnementaux et sociaux.

Cette étude de cas a trait aux métaux présents dans les appareils mobiles. Sont pris en compte, l'antimoine, le béryllium, le palladium et le platine. L'étude de cas est soumise au Groupe de pilotage sur la GDM pour examen et présentation dans le cadre de l'atelier sur la GDM d'octobre 2010.

Qu'est-ce que la gestion durable des matières (GDM) ?

Avant de passer à l'étude de cas proprement dite, il n'est pas inutile de présenter la définition de travail de la GDM (qui est reprise et développée dans l'introduction et dans d'autres documents du SGPDR).

En l'occurrence, la GDM est « une approche destinée à promouvoir une utilisation durable des matières, qui comprend des mesures visant à réduire les incidences négatives sur l'environnement et à préserver le capital naturel tout au long du cycle de vie des matières, sans perdre de vue l'efficience économique et l'équité sociale ». En conséquence, le développement durable est l'objectif suprême et la GDM est le moyen de l'atteindre, en mettant l'accent sur l'intégration des politiques, la prise en compte du cycle de vie, l'efficience et l'équité dans le cadre de l'élaboration et de l'évaluation des mesures destinées à promouvoir l'utilisation durable des matières.

Le casse-tête que pose la GDM tient au fait que les initiatives des pouvoirs publics visant à maximiser l'utilisation durable des matières sont liées à différents « points » du cycle de vie : comme l'illustre le graphique suivant, la question se pose de savoir où commence et où finit la GDM.

Comment les travaux ont-ils été menés ?

Le paragraphe 7 du projet de programme de travail et budget du SGPDR pour 2009-2010 délimite clairement le champ du projet : « *Ces études exploiteraient les données existantes sur les flux de matières dans certains secteurs* ». Autrement dit, même en cas de mise en évidence d'importants déficits de données, il n'était pas question de mener des travaux de recherche originaux pour les combler. Si cela était jugé important, de nouveaux travaux pouvaient être entrepris sous les auspices du SGPDR de l'OCDE. La composition de l'équipe de projet du Gouvernement du Canada est donnée à la section Remerciements, après la table des matières.

À qui le rapport est-il destiné ?

Les destinataires principaux des études de cas sur la GDM sont les responsables de l'action gouvernementale, les dirigeants d'entreprise et les membres de la société civile. Dans certains pays de l'OCDE, le recyclage et les questions connexes sont du ressort de deux, voire trois niveaux d'administration. Pour répondre à la question posée, on pourrait dire que la GDM recherche des solutions de gestion des matières plus en amont dans le flux de produits, et que c'est là le domaine d'intervention naturel des agents nationaux ou même internationaux, qui ont peut-être davantage d'influence en la matière que les communes. Par conséquent, ce rapport est destiné aux décideurs qui souhaitent participer au débat sur les mérites de la GDM.

Quels sont les points clés du rapport dans l'optique de l'action des pouvoirs publics ?

Sur le plan général

- Les avantages et les coûts de l'utilisation ou du recyclage/de l'élimination des téléphones mobiles ne se répartissent pas de façon égale entre les trois dimensions (environnementale, sociale et économique) du développement durable, notamment dans les pays en développement.
- L'approche fondée sur le cycle de vie en matière de gestion de la chaîne d'approvisionnement est extrêmement bénéfique.
- Même si l'on parvenait à récupérer tous les appareils mobiles et à maximiser le recyclage des métaux qu'ils contiennent, il serait nécessaire de mener des activités d'extraction pour répondre à la demande croissante de services fournis par ces métaux.
- Dans le cycle de vie des appareils électroniques grand public, la phase de conception revêt une importance capitale, puisque c'est elle qui détermine le type et la quantité de matières utilisées. Les décisions prises à ce stade ont des répercussions économiques et environnementales directes au moment du recyclage des appareils.
- Comme la plupart des secteurs de l'électronique grand public, celui des téléphones mobiles se caractérise par une formidable aptitude à faire évoluer rapidement les technologies. En particulier, l'introduction de nouveaux matériaux (non métalliques, à base de polymères) peut avoir un impact sur les activités de réutilisation et de recyclage à l'avenir. À cet égard, l'innovation technologique est un important déterminant des politiques.

Sur le plan économique

- Étant donné que les résultats de la planification de la GDM relèvent de trois dimensions différentes (économique, environnementale et sociale), il est très difficile de définir une méthode d'évaluation des coûts et avantages totaux qui soit juste et équilibrée.
- De nombreux produits électroniques grand public conservent une valeur de réutilisation ou matérielle, notamment ceux qui contiennent des métaux; à moins d'être incorporés au flux des déchets et perdus, ces produits peuvent faire et font l'objet d'échanges internationaux; en pensant à l'échelle mondiale et en agissant à l'échelon local, les décideurs nationaux peuvent contribuer à instituer au niveau international une approche globale afin que ces produits et les matériaux qui les composent soient gérés en veillant à une utilisation durable des métaux qu'ils renferment, comme indiqué dans cette étude.
- Le degré de « criticité » d'un métal est largement influencé par sa géographie. En général, les métaux critiques sont extraits dans un nombre d'endroits restreint (ou produits conjointement

avec des métaux de base), mais on les trouve le cas échéant dans d'autres endroits: l'augmentation des prix entraîne l'ouverture de mines.

- L'origine du métal (de première fusion ou de récupération) est fonction des paramètres économiques et de la disponibilité. La valeur économique d'un métal ne reflète pas nécessairement sa criticité et n'est pas forcément corrélée à celle-ci (exemple de l'or).
- La gestion du flux de téléphones mobiles qui ne sont plus utilisés pourrait permettre d'optimiser la valorisation des métaux qu'ils renferment, mais aussi soulever des problèmes commerciaux dans certaines conditions. Les politiques visant à modifier ces flux ou à les contrôler peuvent engendrer des obstacles non tarifaires aux échanges.
- Lors de la phase de conception des produits, différents choix de matières sont envisagés. Il y a un lien direct entre d'une part les possibilités et le degré de substitution de matières, et d'autre part la rareté et les prix.
- Lorsque la rareté se traduit par une hausse des prix des métaux de première fusion, par exemple, le jeu du marché entraîne une forte augmentation du recyclage de métaux et des investissements dans les technologies appropriées.

Sur le plan environnemental

- La qualité des matériaux est déterminée par leur conformité aux spécifications établies.
- La conception avisée des produits, l'efficience économique dans l'utilisation des ressources et une infrastructure de recyclage efficace sont les meilleurs moyens de préserver le « capital naturel ».
- La collecte de l'ensemble des appareils concernés, la réutilisation de leurs éléments ou le recyclage des matières qui les composent contribuent grandement à maximiser le rendement d'utilisation des ressources.
- Le recyclage est une activité économe en énergie qui a pour effet de réduire les émissions de gaz à effet de serre (même si les avantages dépendent de la matière considérée).
- Des installations de recyclage dont le fonctionnement obéit à des normes de gestion écologiquement rationnelles devraient être en mesure de traiter des matières où qu'elles se trouvent et quelle que soit la source des matières. Il est nécessaire d'établir au niveau mondial un inventaire des installations assurant une gestion écologique et capables de traiter des appareils électroniques grand public hors d'usage, et c'est là une idée qui pourrait être soumise au secrétariat de la Convention de Bâle en vue d'un projet futur.
- Le remplacement des composants toxiques et non recyclables peut être envisagé, mais des répercussions défavorables sur la qualité des produits sont possibles, et ce point doit être examiné attentivement à l'aide d'une méthode d'évaluation des risques afin d'éviter des effets négatifs.

Sur le plan social

- Consommateurs, producteurs et pouvoirs publics sont les principaux acteurs concernés par la gestion durable des matières et des produits, mais les deux premiers ne s'inscrivent pas dans la même optique et n'ont pas les mêmes motivations que les pouvoirs publics, pour qui il s'agit d'optimiser les avantages pour les administrés et/ou de réduire au minimum les risques auxquels ceux-ci sont exposés.
- L'analyse sociale du cycle de vie est un outil nouveau qui fait entrer en ligne de compte les conséquences sociales de l'utilisation durable des matières, mais des travaux supplémentaires

s'imposent pour mettre au point cette méthodologie afin qu'elle favorise l'élaboration de politiques plus éclairées.

Principales questions entourant la GDM et premiers éléments de réponse

Quels sont aujourd'hui d'après les estimations les flux de ressources les plus importants (en termes d'incidences environnementales), et comment devraient-ils évoluer ?

À l'heure actuelle, il se vend chaque année dans le monde quelque 1.2 milliard de téléphones mobiles qui représentent un poids de 84 000 tonnes (sans compter les batteries). S'agissant des métaux qui nous intéressent, 84 tonnes d'antimoine (Sb), 7.1 tonnes de béryllium (Be), 12.1 tonnes de palladium (Pd) et 0.3 tonne de platine (Pt) sont utilisés pour fabriquer ces appareils. Premièrement, il n'existe pas actuellement de données sur le cycle de vie en ce qui concerne le Sb et le Be. Deuxièmement, les flux de matières en soi ne peuvent pas être employés comme un indicateur indirect des incidences environnementales. Troisièmement, on ne peut pas traiter la question des incidences sans appliquer des méthodologies de GDM supplémentaires.

Le nombre d'appareils mobiles vendus chaque année continuera d'augmenter. L'évolution de leur poids dépendra des innovations réalisées et de la demande des consommateurs, et certains fabricants signalent que selon toute probabilité, le Be et le Sb cesseront progressivement d'être employés en raison des préoccupations au sujet de leur toxicité/effet sur la santé. Par ailleurs, on s'attend à ce que la demande de Pd et Pt pour d'autres produits, tels que les dispositifs antipollution, augmente, entraînant un renchérissement de ces métaux; dans ces conditions, de nouvelles technologies faisant appel à d'autres matériaux seront vraisemblablement développées. Cela étant, compte tenu de la rapidité des évolutions intervenues ces dernières années, les projections concernant les nouveaux appareils et l'application de nouveaux matériaux sont extrêmement incertaines.

En quoi l'approche fondée sur le cycle de vie peut-elle procurer de nouveaux enseignements et permettre de les traduire en mesures ?

L'approche fondée sur le cycle de vie donne aux recycleurs et aux gestionnaires de déchets la possibilité d'apprécier et éventuellement d'influencer le type et le volume des matières qui traversent le système. En ce qui concerne les appareils mobiles, une meilleure connaissance du cycle de vie peut permettre d'appuyer et de développer les activités actuelles de réutilisation et de recyclage. En particulier, la collaboration entre recycleurs et concepteurs de produits constituerait un moyen intéressant de combler le fossé qui semble les séparer: par la compréhension des interactions et des relations de dépendance inhérentes aux étapes du cycle de vie que sont la conception, la production, l'utilisation, la réutilisation et le recyclage, il peut être possible de mettre en évidence de nouvelles mesures d'amélioration de l'efficience.

Quelles mesures ont été prises ou peuvent être prises par les pouvoirs publics pour favoriser des résultats compatibles avec un développement durable ?

Le recyclage permet un traitement des matières plus économe en énergie. L'action des pouvoirs publics devrait mettre l'accent sur le lien entre économies d'énergie, amélioration des facteurs économiques et abaissement des émissions de GES. Afin d'améliorer les rendements de recyclage et de réduire l'exposition des travailleurs, les politiques de gestion des risques consistent notamment à sensibiliser et à définir des normes. Les fabricants commencent à abandonner peu à peu certaines matières contenues dans les téléphones mobiles dont on a établi qu'elles posent des problèmes aux recycleurs (le Be et le Sb, par exemple). La conception dans l'optique du recyclage est théoriquement souhaitable et peut être encouragée par l'adoption de mesures instituant entre autres la responsabilité élargie des producteurs (REP) ou la responsabilité individuelle des producteurs (RIP). L'expérience montre que là où l'action des pouvoirs publics a débouché sur des programmes de REP, les taux de récupération des produits sont généralement en hausse. Il s'agit sans doute de la meilleure approche pour gérer les produits grand public hors d'usage comme les appareils mobiles. En fait, la plupart des fabricants d'appareils ou fournisseurs de services mobiles proposent sous une forme ou une autre un programme de reprise de ces produits: le défi consiste à faire en sorte que le grand public y participe. Étant donné que la durée de vie de ces appareils va diminuant, des systèmes de consigne ou des formules originales de location pourraient constituer un bon moyen d'accroître les taux de collecte. L'interdiction de l'élimination des appareils en question au niveau national ou régional envoie un message fort au public, mais elle risque en fin de compte d'être inapplicable et même inutile si des infrastructures de recyclage idoines ne sont pas en place. Étant donné que la durée de vie technique d'un téléphone mobile est d'environ dix ans, les mesures publiques incitant les utilisateurs à garder plus longtemps leur téléphone vont *in fine* dans le sens de l'utilisation durable des matières. Des prescriptions relatives à la longévité des produits pourraient être incorporées dans les cahiers des charges définis pour les marchés publics; ou bien, les durées d'utilisation des équipements électriques et électroniques dans l'administration pourraient être rallongées. L'approche la plus efficace consiste sans doute à associer plusieurs politiques et programmes. Des informations complémentaires au sujet des mesures déjà en vigueur ont été présentées dans un autre rapport de l'OCDE intitulé « *Inventory of International Initiatives Related to Sustainable Materials Management* » (septembre 2008): les initiatives en question portent entre autres sur la responsabilité sociale des entreprises, les politiques intégrées en matière de produits, les centres de production propre, les marchés publics écologiques, l'éco-étiquetage et la REP.

Dans quelle mesure différents acteurs de la société s'engagent-ils dans des initiatives promouvant un comportement responsable afin d'œuvrer activement en faveur de résultats compatibles avec un développement durable?

De nombreuses activités sont en cours sur différents aspects touchant aux produits électroniques grand public en particulier, et aux métaux en général. À la page 36 du document "Critical Metals Case Study Annexes", la figure 3 recense 25 initiatives de portée internationale (MPPI, PACE, GeSi, StEP, etc.) ou nationale (Canada, Australie…). Parmi les termes employés dans les intitulés de ces initiatives, on trouve « responsable », « bonne gestion », « engagement », « durabilité », « coalition » ou encore « partenariat ». Plusieurs questions se posent : 25 initiatives, est-ce trop ou trop peu? Comment ces programmes sont-ils suivis et évalués? Sont-ils performants (résultats obtenus)? Sont-ils d'un bon rapport coût-efficacité? Pourquoi ont-ils été mis en place à l'origine? Rassemblent-ils les bons partenaires? Qui finance ou soutient ces activités? Voilà autant de bonnes questions qui appellent des réponses.

Quels sont les principaux déficits de connaissances?

- On sait très peu de choses du flux mondial des téléphones mobiles qui sont destinés à être réutilisés ou recyclés.
- Les données sur le cycle de vie concernant certains métaux critiques sont sommaires.
- Les données relatives aux émissions de GES et à la consommation d'énergie qui ont été réunies pour cette étude de cas ont été agrégées au niveau des phases d'extraction/affinage et de fabrication: des ensembles de données distincts pour chaque phase sont nécessaires.
- Peut-on mesurer les coûts sociaux cachés des processus de production/recyclage des téléphones mobiles et des métaux critiques?

- Comment comparer les avantages économiques et sociaux des appareils de communications mobiles et les incidences environnementales et sociales d'une élimination ou d'un recyclage contre-indiqué de ces appareils?
- Pourquoi les utilisateurs de téléphones mobiles conservent-ils les appareils qu'ils n'utilisent plus, et quel est le meilleur moyen de faire participer les consommateurs aux programmes de collecte prévus ou déjà en place?
- Quel est le coût moyen de reconditionnement d'un téléphone mobile et quel est le rapport de substitution entre téléphones mobiles réutilisés et téléphones mobiles neufs?
- Quelle est l'importance du secteur informel du recyclage des produits électroniques grand public?
- De nouvelles analyses économiques sont nécessaires pour améliorer la comparaison entre les activités de recyclage informelles (de faible technicité) et celles mettant en jeu des opérations de fusion (procédés intégrés de pyrométallurgie).
- Les connaissances scientifiques doivent être approfondies pour mesurer le risque posé par l'élimination finale des téléphones mobiles dans des décharges aménagées et des incinérateurs « de pointe » dotés de dispositifs antipollution (par opposition aux décharges et aux incinérateurs rudimentaires dont les dispositifs antipollution sont insuffisants ou inexistants).

À quoi peuvent servir les conclusions du rapport ?

Les conclusions du rapport sont résumées dans la section sur les points clés dans l'optique de l'action des pouvoirs publics et dans la section précédente sur les principaux déficits de connaissances. Ces deux domaines sont au centre de la présente étude de cas. On trouvera plus de détails sur l'un et l'autre dans les sections 4 et 5 du rapport principal.

Dans ce rapport, quatre méthodologies de GDM (analyse des flux de substances, évaluation du cycle de vie, éco-efficience et cadre proposé pour l'incorporation des aspects sociaux) sont utilisées pour détailler l'état des connaissances concernant la source et le devenir des métaux critiques contenus dans les téléphones mobiles. Les téléphones mobiles doivent être considérés comme une variable représentative des autres produits électroniques grand public, même s'il est admis que leur poids relatif dans le flux des déchets solides mis en décharge et incinérés dans le monde, bien qu'en augmentation rapide, est aujourd'hui très faible (moins de 0.1 % du total en poids au Canada).

Même si les quantités en jeu sont faibles, la présence dans les téléphones mobiles de métaux de valeur, à la fois précieux et critiques, retient largement l'intérêt. Ces métaux posent-ils un risque en cas d'abandon dans l'environnement? Leur valorisation vaut-elle la peine? Quels sont les facteurs qui favorisent un recyclage accru et ceux qui y font obstacle? Voilà quelques-unes des questions que les décideurs devraient se poser afin de mieux cerner les modalités d'application de la GDM. Une autre démarche pourrait consister à assurer une concertation nationale afin de sensibiliser les intéressés au concept et de susciter de leur part un retour d'informations sur son utilité.

Les responsables de l'action gouvernementale n'envisagent pas tous de la même façon le caractère critique des métaux utilisés dans les appareils électroniques grand public. Ce rapport montre que la notion de criticité est subjective, liée à la géographie et susceptible de varier dans le temps. À la base de cette notion, il y a l'idée de « motif ». Les déterminants de la criticité sont principalement d'ordre commercial ou économique. Les nations productrices ont intérêt à assurer la pérennité des approvisionnements en métaux nécessaires pour fabriquer les biens économiques dont dépend leur bien-être économique et social à un prix qui permette de préserver leur compétitivité internationale. Une soudaine interruption des approvisionnements en métaux réputés « critiques » pour certaines applications peut entraîner d'importants bouleversements économiques et sociaux. Ainsi, la criticité peut être liée à la « disponibilité » et à la demande. Lorsqu'il s'agit d'un enjeu ou d'une application « stratégique », c'est-à-dire lié à la défense nationale, le coût est rarement un facteur déterminant. Dans ce document, nous ne tentons pas d'exposer le raisonnement qui sous-tend l'identification des métaux critiques, car celui-ci varie selon les pays et dans le temps.

Voici quelques-unes des conclusions importantes de cette étude: premièrement, la collecte des téléphones mobiles usagés doit être grandement améliorée au Canada et dans d'autres pays de l'OCDE. Deuxièmement, la phase de triage qui suit la collecte optimise la réutilisation des appareils, ce qui est déterminant pour la viabilité économique de ces activités. Troisièmement, les fabricants d'appareils préféreront peut-être encourager le recyclage plutôt que la réutilisation, car cela leur permet de vendre davantage de produits neufs. Quatrièmement, les intervenants qui assurent les étapes de traitement intermédiaires jouent un rôle important, le démontage des appareils usagés permettant la réutilisation des pièces, le retrait des polluants et la valorisation des matériaux. Cinquièmement, les installations qui sont gérées de façon efficiente et parviennent à maximiser les rendements de recyclage devraient être assez compétitives sur le marché mondial pour s'approvisionner en quantités suffisantes (téléphones mobiles hors d'usage compris), même si les entreprises fonctionnant selon des normes moins contraignantes faussent la concurrence. Les interventions publiques visant à assurer l'approvisionnement de pays producteurs de téléphones mobiles en certains métaux iraient à l'encontre de l'engagement général de l'OCDE en faveur de l'économie de marché et de l'objectif qui prévoit d'aider les autres pays à assurer leur développement économique. Sixièmement, sachant que le recyclage informel dans les pays en développement a des effets dommageables sur l'environnement et la santé, il est impératif de renforcer les capacités de gestion écologique, car le nombre d'usagers de la téléphonie mobile augmente très rapidement en Asie et en Afrique.

Pour soutenir des activités de GDM telles que la collecte et le recyclage des téléphones mobiles, les pouvoirs publics peuvent intervenir sur l'ensemble du cycle de vie de ces appareils. La portée et l'ampleur de ces interventions varieront selon les pays de l'OCDE, en fonction des préoccupations politiques et de la « culture » de chacun. Le cas extrême est celui où les pouvoirs publics parviennent à appuyer ou même à rendre obligatoire la conception dans l'optique du recyclage au travers d'échanges de vues avec l'industrie sur la REP; toutefois, il s'agit là d'un défi de taille pour les pays qui ne comptent pas beaucoup de fabricants. On peut aussi imaginer que les discussions menées avec les entreprises de télécommunications dans le cadre d'instances comme l'Initiative pour un partenariat sur les téléphones portables (MPPI) débouchent sur des initiatives volontaires tournées vers la réalisation des mêmes objectifs (par exemple, retrait du béryllium des téléphones mobiles dans un souci de sécurité et de protection de la santé des travailleurs). Une autre étape du cycle de vie où une intervention des pouvoirs publics peut être efficace est celle où l'utilisateur doit décider de ce qu'il fait d'un téléphone qui ne lui sert plus. À ce stade, si l'utilisateur peut récupérer une consigne payée lors de l'acquisition du téléphone ou si l'élimination de l'appareil est interdite, par exemple, on peut espérer un accroissement du taux de collecte et donc des activités de recyclage. On trouvera un examen plus approfondi des principes d'action et des instruments de la GDM dans les documents thématiques préparés pour le Sous-groupe de l'OCDE sur la prévention de la production de déchets et le recyclage (SGPDR).

Le choix de quatre métaux critiques présents dans les téléphones mobiles a été fait dans le but de circonscrire l'analyse. En volume, l'industrie électronique dans son ensemble représente 5% de la consommation annuelle mondiale de platine, 16 % de celle de palladium, 50 % de celle d'antimoine et environ 7 % de celle de béryllium (sous forme d'alliage cuivre-béryllium). Le bouquet de métaux employés dépend des produits et varie continuellement en raison de l'évolution des technologies dans le temps. L'économie mondiale continuera de solliciter les stocks de métaux disponibles: cette demande est changeante et les marchés mondiaux permettent le plus souvent d'y répondre. Peut-être les décideurs devraient-ils examiner comment le processus de GDM pourrait influencer le marché dans le sens d'une optimisation de l'utilisation des ressources peu abondantes.

Quelles sont les prochaines étapes?

Il convient indéniablement de redoubler d'efforts pour améliorer la connaissance des flux de téléphones mobiles hors d'usage. Les responsables de l'action gouvernementale pourraient mener des échanges de vues à ce sujet avec le secteur des télécommunications mobiles pour déterminer s'il existe déjà des systèmes de suivi viables: peut-être la solution consiste-t-elle simplement à consolider des informations disparates. Il est sans doute préférable de laisser la coordination des activités nationales de suivi aux acteurs du secteur: fabricants, détaillants, organismes de collecte et entreprises assurant les opérations de reconditionnement, de recyclage ou de fusion. Ce sont peut-être les « marques » du secteur de la téléphonie mobile qui sont les mieux placées pour jouer ce rôle de coordination, et elles ont d'ailleurs apporté d'importantes contributions à l'Initiative pour un partenariat sur les téléphones portables de la Convention de Bâle (MPPI).

Un examen plus approfondi mériterait d'être mené pour mieux comprendre ce que les utilisateurs font des téléphones mobiles arrivés en fin de vie ou perçus comme tels. Les pouvoirs publics pourraient réaliser des enquêtes auprès des consommateurs pour déterminer pourquoi les systèmes de collecte existants ne sont pas utilisés. Ils devraient aussi coopérer avec les acteurs du secteur énumérés dans le paragraphe précédent afin de tirer les enseignements de l'expérience et de mettre en évidence les pratiques exemplaires. Ce travail est en cours.

De tous les instruments qui entrent dans le cadre de la GDM, on peut penser que c'est l'approche fondée sur le cycle de vie qui revêt la plus grande importance. Elle n'est plus l'apanage des universitaires. Dans le monde de l'entreprise est souvent évoqué le « triple bilan » (économique, social et environnemental), qui favorise le développement durable et la responsabilité sociale des entreprises. Dans le contexte de cette étude de cas, il se peut que des fabricants de téléphones mobiles qui adhèrent au principe de triple bilan se livrent à des activités de GDM sous une autre appellation. En assurant la promotion de ces « entreprises de tête » ou « meilleurs élèves », les gouvernements nationaux ou les organismes internationaux joueraient un rôle utile. C'est ainsi qu'il sera possible de faire véritablement entrer dans les mœurs l'approche fondée sur le cycle de vie.

Même s'il n'examine pas en détail cette idée, le présent document laisse entendre que la criticité d'une matière peut être influencée par l'existence de solutions de substitution. Le recours à des matières de remplacement est lui-même influencé par divers paramètres sociaux et économiques, ainsi que par le progrès technique. Si les pouvoirs publics entendent encourager des substitutions dans un souci de protection de l'environnement ou de la santé humaine, ils devraient appliquer les mesures correspondantes au cas par cas, sur la base de données scientifiques et d'évaluations des risques solides, et après avoir évalué également les risques associés aux matières de substitution potentielles. La question de savoir pourquoi et quand une matière est remplacée par une autre présente de l'intérêt pour les responsables de l'action gouvernementale, et dans ce contexte il serait possible de mettre en pratique certains des principes et des politiques de GDM qui ont été mis en évidence par ailleurs. Il est généralement admis que les substitutions de matières réalisées dans l'industrie le sont avec beaucoup de précaution et de manière étalée dans le temps, de façon à éviter des erreurs qui risqueraient de compromettre le processus de production, le bon fonctionnement des produits et la nécessaire rentabilité.

1. INTRODUCTION

1. The Working Group on Waste Prevention and Recycling (WGWPR) of the Organisation for Economic Co-operation and Development (OECD), as part of its Sustainable Materials Management (SMM) initiative, has initiated cases studies on four materials: aluminum, “critical” metals, wood fibres and plastics. The overarching goal in undertaking these studies is to explore policy opportunities for and barriers to implementing SMM, in each area, as a way of evaluating its utility for broad policy-making.

2. The WGWPR has studied a number of methodologies that are relevant to SMM[1]. This case study examines four of these approaches – substance flow analysis (SFA), life cycle assessment (LCA), eco-efficiency and social aspects framework.

3. Even though the working definition of SMM that has been proposed by the Working Group at the first OECD workshop on SMM recognized the need to include social aspects, the main focus of the definition remains on the economic and environmental aspects. Indeed the same can be said for many other SMM initiatives, tools and methodologies. It is likely though that there will be increased importance given to the integration of social, economic and environmental elements into sustainable materials management. There is presently no initiative within SMM that is trying to address the diversity of social challenge within the life cycle of materials.

4. Critical metals have many applications, with a significant proportion of available supply taken up by consumer electronics (depending on the metal). Given time and resource constraints, the scope of this work was narrowed, with mobile phones selected so that an analytical framework could be developed to help policy makers. That framework can be modified in order to address SMM challenges associated with other consumer electronic products. Mobile phones contain printed circuit boards that have metals of high economic value and these boards are also being found in an increasing number of other consumer products (with varying life spans). Since mobile phones correlate with wireless subscription services, the number of mobile phones in use is generally well known. There are a number of additional reasons why critical metals and mobile phones represent a good case study for evaluating SMM tools:

- The composition of mobile phone is similar to the composition of circuit boards used in computers and other consumer electronics or electrical devices,
- The life of mobile phones for the first user is decreasing (about 18 months now),
- Market penetration is increasing,
- The flow of North/South trade in reusable and recyclable mobile phones is growing,
- Like other commonplace high tech products, mobile phones, smart phones and personal digital assistants play an increasingly important social and economic role in the global economy,
- Certain metals are essential in the performance of these products, and importantly,
- There is a recognised need to assess the management of materials and products throughout their life cycle.

5. By using SFA and LCA to analyse selected critical metals in representative consumer devices, this study should help to determine if SMM tools can help inform policy decisions that optimise resource efficiency.

1.1. Objectives

6. Using selected SMM tools, this study examines the source and fate of critical metals contained in mobile phones. The main outputs include:

- A summary of key findings to date regarding the environmental, economic and social dimensions of electronic devices over the whole life cycle;
- An inventory of knowledge gaps by assembling and engaging a panel of experts; and,
- An assessment of key options, barriers and jurisdictional issues

1.2. Background and report structure

7. The case study on critical metals was separated into two work phases. In Phase 1, a literature review was undertaken, pertinent SMM methodologies were assembled and available data were gathered and analyzed. The primary purpose of the Phase 1 work was to identify knowledge gaps and to provide an outline for the remaining work. A useful step in this project was the creation of an advisory group (see Annex 3 of document "Critical Metals Case Study Annexes" with which to conduct "roundtable" analysis. This group was composed of academic, industrial, institutional and consultant experts in LCA, mobile phones and critical metals. A draft of the Phase 1 report was used to elicit their feedback. In the final report, these gaps are identified throughout Section 3 and summarized in Section 4. The final report includes policy considerations that at one level are embedded in the life cycle discussion of mobile devices (throughout Section 3) and then summarized, in response to issues raised by the SMM Steering Committee. Section 5 presents a summary discussion of possible policy barriers and opportunities.

1.3. Case study context

1.3.1 What makes a metal critical?

8. There is no standard definition of the term "critical metals". When this case study proposal was being developed for the SMM Steering committee, some discussion took place concerning the need to focus on "critical", "strategic", "rare" or "speciality" metals. The difference between these terms is subtle in some cases but specific in others.

9. For the U.S. Congress, strategic and critical materials were defined in 1983 as "those that are needed to supply the military, industrial, and civilian needs of the United States during a national defence emergency and whose supplies are dependent on imports."[2] The essence of this policy perspective that is shared with other countries could also be described as "security of supply" with attendant economic implications and concerns. More recently, the U.S. Department of Defence has stated "speciality metals are not 'critical metals.' There is no national security reason for the Department to take action to ensure a long term domestic supply of speciality metals."[3] The distinction between strategic, critical and a specialty metal is articulated further (same reference) as follows:

> *The designation of a strategic material should be predicated on it meeting a "technical" criterion: the material should be essential for important defense systems and unique in the function it performs—there are no viable material alternatives available.*

Critical materials are a subset of strategic materials. The Department of Defense should designate a material as "critical to national security" only if it meets the "technical" criterion of a "strategic" material; and also meets two additional criteria:

- *"Business" criterion: The Department of Defense dominates the market for the material, and its active and full involvement and support is necessary to sustain and shape the strategic direction of the market; and*

- *"Security of Supply" criterion: There is significant and unacceptable risk of supply disruption due to vulnerable U.S. or qualified non-U.S. suppliers.*

The Department agrees that strategic materials, including specialty metals, are essential for important defense systems, and in many cases are unique in the functions they perform. Therefore specialty metals are considered strategic materials. However, specialty metals do not meet the other criteria necessary to be considered critical materials

10. For the Resource Efficiency Knowledge Transfer Network of the United Kingdom, the term "material security" means, "there is no significant disadvantage to the national economy or national defence caused by a restricted access to specific materials."[4] Their assessment of material security includes material risk (global consumption, sustainability, global warming potential (re: greenhouse gas [GHG] emissions[1]), total material requirement) and supply risk (scarcity, monopoly supply, political stability, climate change vulnerability). The authors analysed sixty-nine minerals and metals and concluded that gold, rhodium, mercury, platinum, strontium, silver, antimony and tin were on the top of the list.

11. In 2007, the German Environmental Agency commissioned a study on rare metals.[5] According to that study, rare metals are defined as (1) expensive or whose price has increased dramatically, (2) having a low current availability, and (3) being extracted in only a few countries. It was further observed that the rare metals used in "information and communications technology products" are antimony, cobalt, gold, indium, palladium, platinum, rhenium, tantalum, tin and zinc.

12. Building on the British and German analyses, broader European interest in "strategic resources" further highlights the economic, social and political importance of metals. The sub-title for one Euromines' 2008 presentation is "The Raw Materials Initiative – Meeting Our Critical Needs for Growth and Jobs in Europe."[6] Some of the elements of interest are the nearly fifty metals that are considered in the context of "high tech" rather than "conventional" applications. In this regard, specific mention is made by Euromines of "super alloys, semiconductors, catalyst, lighting, batteries and magnets." However and unfortunately, their list of metals of interest is not ranked according to specified criteria such as supply risk.

13. Industries and R&D activities that rely on new and emerging information and communication technologies (ICT) technologies are the rising stars of the "new economy" and many of their components are composed of metals with special properties. To understand how critical metals are produced, the *ecoinvent* report[7] on metals provides an excellent overview. For this case study, critical metals have been defined as those which:

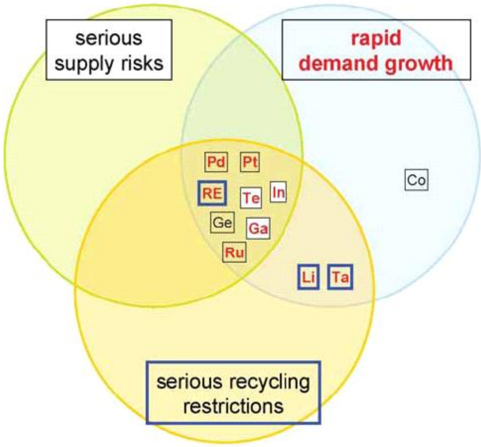
- Perform an essential function for which there are few or no satisfactory substitutes;
- Are associated with economic, social and other consequences if these essential functions cannot be delivered;
- Command significantly higher prices if supply of the material is restricted; and,

[1] Refer to the International Panel on Climate Change for a discussion of GHG and its global warming potential.

- Aggregate demand for key applications represents a relatively high proportion of the overall supply of material that meets the required specifications.[8]

14. The Öko-Institut e.V. completed a report for UNEP[9] on critical metals in 2008.[10] The study looked at metals used in clean or environmental technologies such as energy-efficient batteries and lights, fuel cells and photovoltaic cells. Figure 1 illustrates the prioritization process used for the UNEP project. In Figure 1, the metals in the centre area would be ranked as the most critical given the understanding that their supply is weak, demand is high or growing, and certain restrictions makes their recyclability difficult.

Figure 1: Critical metals used in future sustainable technologies according to the Öko-Institut



15. To better understand the dynamics of supply risk, the availability of primary mineral and of secondary resources (*i.e.* recycling) needs to be assessed. The long-term availability of primary minerals and metals is influenced by a number of key factors: geology, technology, environmental concerns, social issues, policy (government direction) and economics. Broadly speaking, each of these factors represents a potential barrier to or opportunity for the implementation of SMM over a material or product's life cycle. The same factors influence the long-term reliability of supply of recyclable materials although, instead of geology (where is the ore?), it is the material flow of end-of-life products (where are the sinks?) that is of interest.

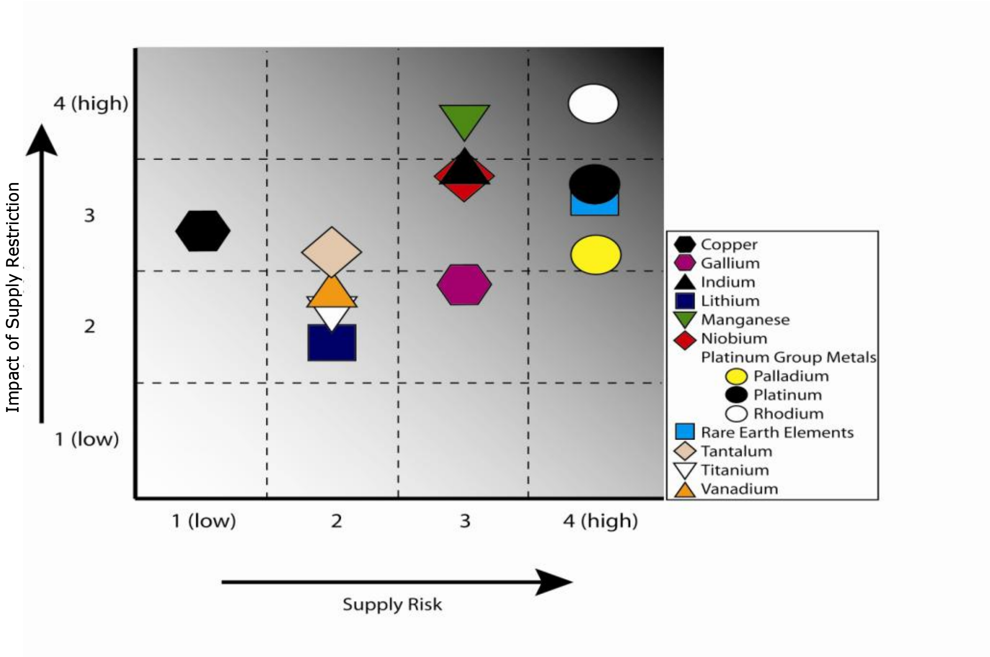
16. For the short or medium term, factors that can influence supply risk are:

- A sudden increase in demand if production is already close to capacity,
- A relatively thin market where demand is concentrated in a small number of applications,
- A large capacity of production concentrated in a small number of countries,
- A significant supply of metals comes from by-product production, and
- The lack of recovery of material from post-consumer scrap.

17. The other dimension to consider is the impact of supply restriction. Metals are used because they serve a special purpose (or in life cycle language, they "deliver a function"). A main determinant of their criticality is the concept of *substitutability*. If a material B that is more available can replace Metal A with similar function and price in a given application, then Metal A is less critical. For example, fibre optic cable composed mainly of silicon oxide displaces copper wire for some communication requirements.

18. The Committee on Critical Mineral Impacts on the U.S. Economy developed an analytical matrix to assess criticality which they tested using selected materials. The results presented in Figure 2 indicate that indium, manganese, niobium, PGMs[2] and rare earth elements[3] (REE) fall into the critical zone of the matrix: Palladium and platinum are used in mobile phones. The Committee also noted "All minerals and mineral products could be or could become critical to some degree, depending on their importance and availability."[11]

Figure 2: Criticality matrix for thirteen materials



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19. Resource-based economies are likely to view the concept of 'criticality' differently than manufacturing and resource-importing countries. Instead, the concerns surrounding access to and supply of "critical metals" should be viewed as presenting an opportunity for new economic activity. Although global supply of precious or specialty metal mine production may currently be dominated by a few countries, even if accompanied by competitive advantages (*i.e.* lower wages, fewer environmental controls, etc.), if supply cannot meet market demand, prices will rise and – as a direct result – new or closed mines will open/reopen in other locations and recycling activities will expand. In effect, the world may be far richer in mineral wealth than is reflected by current production.

20. The term "critical metals" therefore is unlikely to have a common universal meaning since the list of critical metals varies with the methodologies used, the assessment criteria applied and the extent of analyses undertaken. In summary, the definition of critical metals is a value judgement that is based on the perspective of individual countries. This nationalistic viewpoint is a function of its mineral endowment and of its technological infrastructure. For practical reasons, the scope of this case study has been limited to a short list of "critical metals" that are (a) exposed to potential supply risk, (b) subject to supply restriction

[2] Platinum Group Metals = Platinum, palladium, rhodium, ruthenium, iridium, osmium

[3] Rare Earth Elements = La, Ce, Pr, Nb, Pm, Sm, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Y

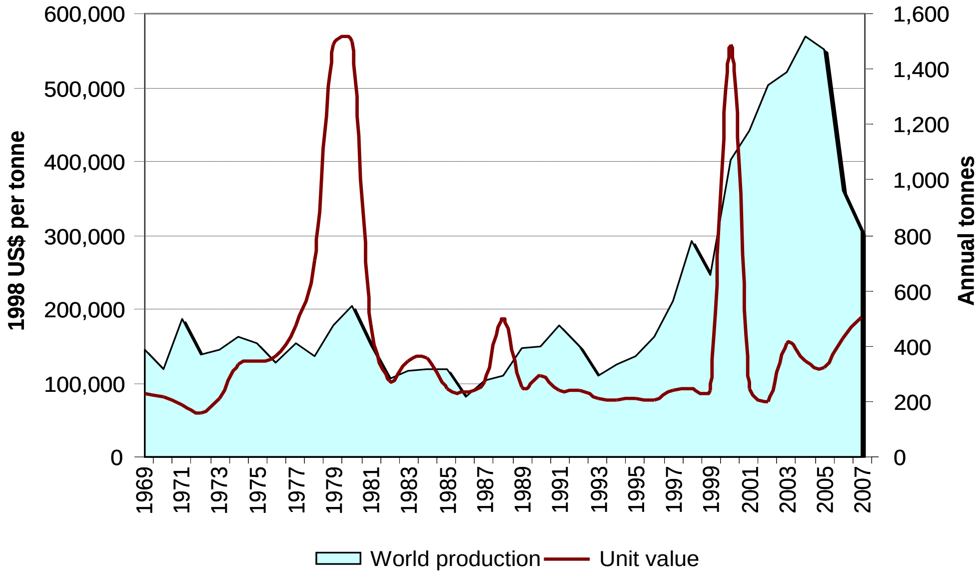
and (c) found in mobile phones. Further work could be undertaken by the SMM Steering Committee to add other metals to this analysis.

1.3.2. Is the criticality of a metal fixed in time or dynamic?

21. Tantalum[12] is used as a minor element with cobalt, nickel and iron to make super alloys used in aerospace structures, jet engine components and many other items. However, more than half of global tantalum metal in 2003 was used to make capacitors. High performance capacitors are instrumental in the development of mobile phone technology, miniaturized cameras and personal computers because they reduce energy consumption. The explosive demand for tantalum in the late 1970's induced a rapid increase in the price of tantalum while its production was reduced due to conflicts in the Democratic Republic of Congo (see Figure 3)[13].

22. The conflict in Congo was aggravated by the search for mineral wealth to fund competing militias: the extraction of the ore containing the tantalum ("coltan" or columbo-tantalite) was caught up in these struggles. Subsequent and intensive research led to substitutes. In particular, capacitors based on aluminum and ceramics were developed. While these substitutes were not as efficient as the tantalum based ones, they effectively reduced the demand for tantalum in less exacting applications. As a result, the "impact of supply restriction" was reduced. Further, as new mining reserves were developed and as new mining capacity brought on stream, mainly in Australia, the supply risk decreased. This is clear evidence that the criticality of any given metal is indeed dynamic in an open, transparent market context. A metal can move along either one or both axes of the analytical matrix (Figure 2) over time, in response to changes in conditions.

Figure 3: Tantalum – World production and value, 1969 - 2007



1.3.3. What is the geographical profile of critical metals?

23. As noted previously, a supply risk can occur when a single country dominates the mining production of one commodity. In Figure 4 countries are identified that occupy a principal position in the mining and production of some selected metals. For example, ninety percent of the global production of niobium is in Brazil. Niobium is used in various advanced engineering systems, nuclear industries and super conductive magnetic applications. For manufacturing economies that depend on niobium imports,

any disruption in its supply chain could have large dislocating effects (*e.g.* business closure, job loss, market shrinkage, etc.).

24. The purpose of this illustration is to highlight where some of the potentially critical metals are produced. Table 1 identifies estimated world base reserves for other metals that occupy the critical zone presented in Figure 4[14]. Table 1 also identifies the world's number one and number two producers (countries of origin) in order to illustrate the degree of geographic concentration of these reserves.

Figure 4: Countries having a dominant mining production of some metals

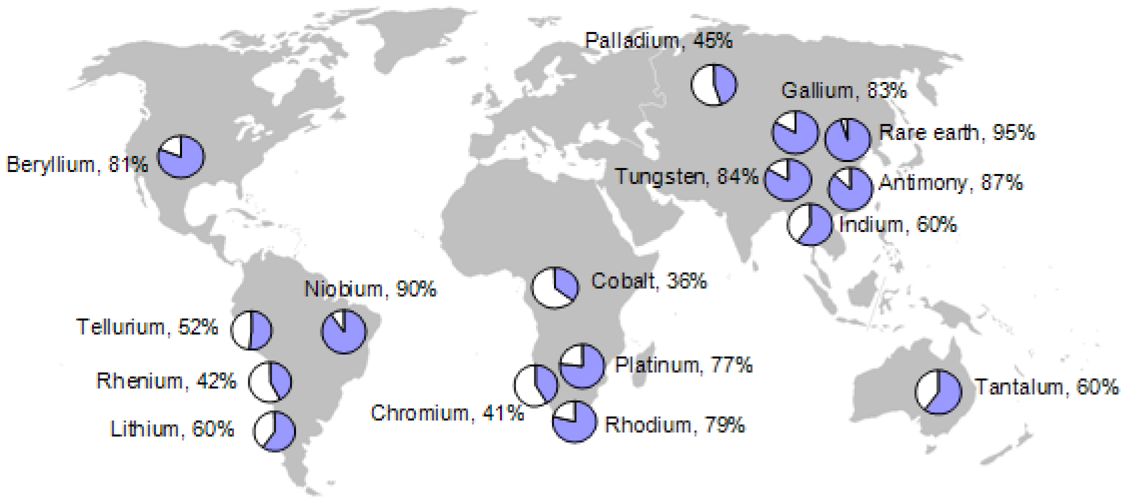


Table 1: World Reserves for antimony, beryllium, palladium and platinum

Critical Metal	World Reserves (kilo-tonnes)	Number 1	Number 2
Antimony	2,100	China (87%)	Boliva (3%)
Beryllium	80	United States (81%)	China (11%)
Palladium*	100	Russia (45%)	South Africa (39%)
Platinum*	--	South Africa (77%)	Russia (11%)

*World reserves for Pd and Pt combined as Platinum Group Metals

25. What are "world reserves"? A mineral reserve is a dynamic concept because its magnitude is heavily influenced by technical, economic and political realities. Higher demand and metal price leads to more exploration and expanded reserves. It is therefore misleading to think in terms of "peak" metals: the basis for the peak keeps changing. However, the inclusion of world reserves in Table 1 provides global production context only and is not intended to support a comparison of these metals.

1.3.4. Why were mobile phones considered for analysis?

26. Mobile phones are becoming increasingly numerous, materially complex and seemingly indispensable. In general, their life span is declining while they shrink in size though their functionality has improved. A guidance document prepared as part of the Basel Convention's Mobile Phone Partnership Initiative[15] (MPPI) describes the evolution in mobile phone size that, once 5 kilograms in weight in 1984, have now shrunk to 75 grams by 2001 (or 100 grams if the battery is included).

27. Like mobile phones and circuit boards, the technology for batteries is also evolving. The three main battery types are lithium-ion, nickel-metal-hydride and nickel cadmium (and according to MPPI, there is a move away from the latter because of concerns regarding toxicity towards the former two that have higher energy densities). However, end-of-life batteries are excluded from the scope of this case study because they undergo completely separate treatment when recycled in specialised facilities.

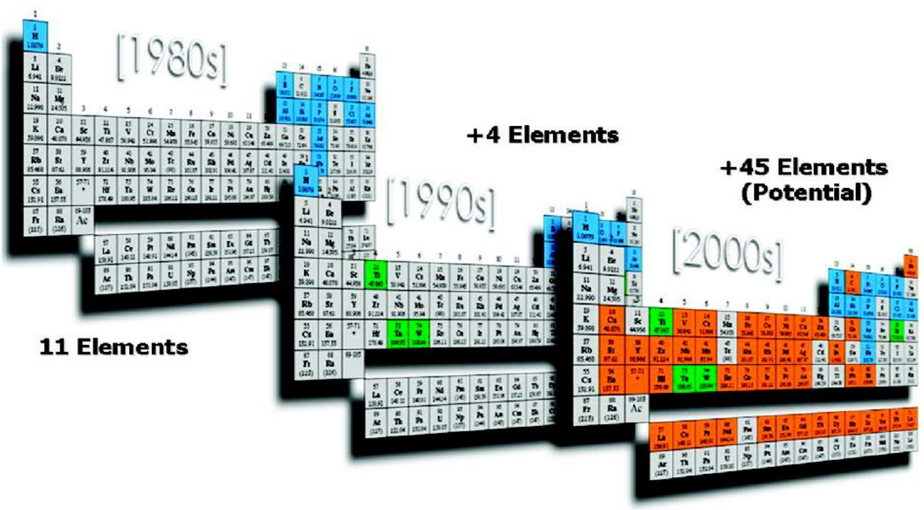
28. From a policy perspective, therefore, mobile phones are of interest because of their critical constituents and what happens to them when they expire: in this regard mobile phones are intended to be a surrogate for any consumer electronic or electrical product that contains printed circuit boards. A sufficient amount of data regarding the composition of printed circuit boards and mobile phones is available for this case study.

29. From a policy perspective, the design, production, use, durability, obsolescence and end-of-life management of mobile phones may present opportunities for (1) regulatory support or intervention and (2) voluntary, industry led initiatives. While such policy opportunities are addressed in Section 5, more data need to be assembled to analyse end-of-life mobile phones and to compare their likely fate (discard) with their preferred fate (recycling): the comparative implications of extracting critical metals from raw materials (*i.e.* primary resources) would help complete this analysis.

1.3.5. Which materials are contained in a mobile phone?

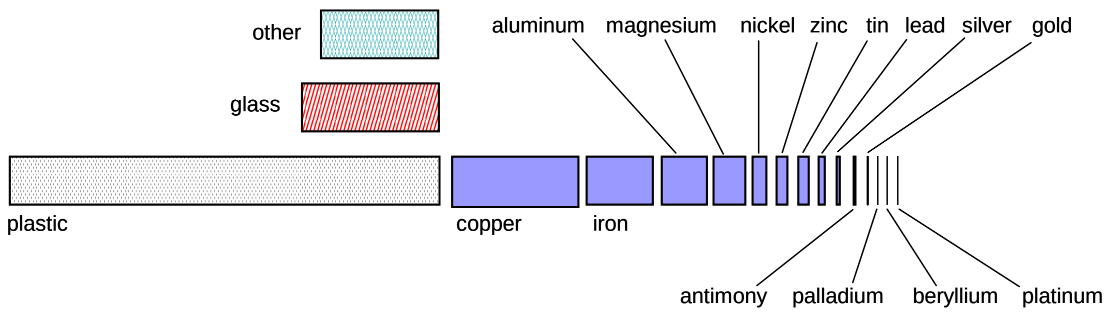
30. Circuit boards reflect the growing complexity of consumer electronic devices, as illustrated in figure 5[16]. Mobile phones are also becoming more complex in terms of their functionality, design and material composition. According to Nokia, from 500 to 1000 different components are contained within a single mobile phone.[62] Given current trends, it is anticipated that new materials will be invented to supplant those that are in use now.

Figure 5: Circuit board elements over time



31. A typical mobile phone (excluding battery and accessories) contains plastics (43%), glass (14%), copper (13%), iron (7%), aluminium (5 %), magnesium (3%) and silver (0.35%). Nickel, tin and lead are all about 1% with gold in an amount less than 0.04% (276-446 ppm[4]). For practical reason the list of critical metals of interest is limited to four: antimony (0.1%), palladium (<0.02%), beryllium (<0.01%) and platinum (<0.01%). Cobalt might have been included if batteries had been considered to be inside the scope of the study. Tantalum is not considered due to technological improvements, reduced use of Ta in mobile phones and increased mining capacity. Figure 6 presents the material content of a mobile phone.[17]

Figure 6: Material content of a mobile phone (by weight)

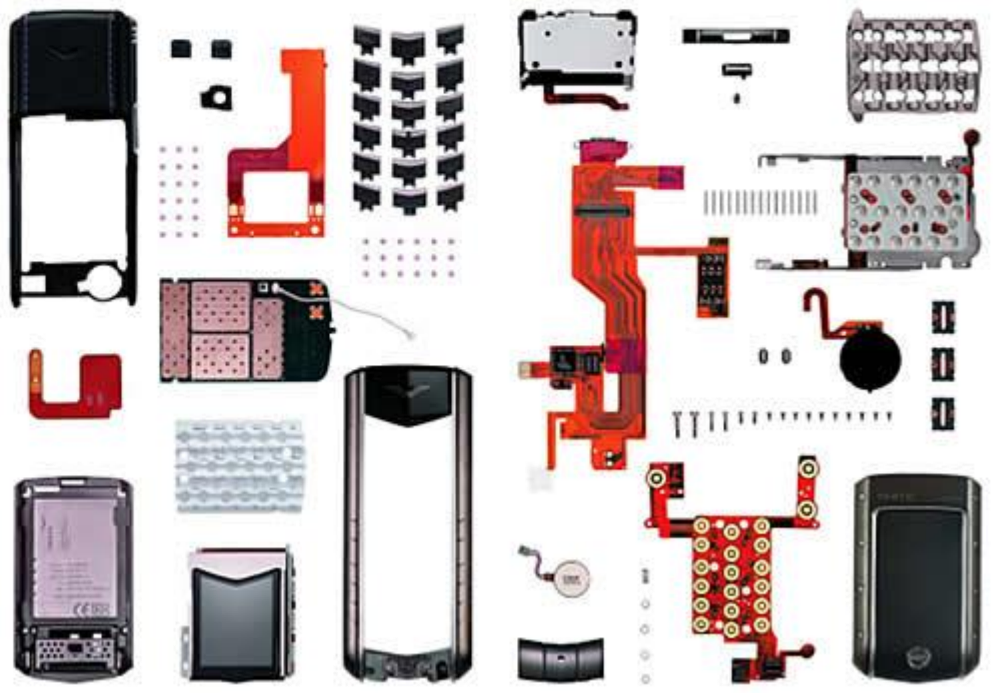


32. It is estimated that there are 3.378 billion mobile phones in use around the world and that this figure may have reached 4 billion by the end of 2008.[18] At present, the annual sale of new mobile phones is estimated to be 1.2 billion.[19] Therefore, at 70 grams per unit (battery excluded), it is estimated that 84 kilo tonnes of mobile phones are produced annually. At the percentages identified above, the annual amount of critical metals needed to make these devices is estimated as follows: antimony, 84 tonnes; beryllium, 7.1 tonnes, palladium, 12.1 tonnes; and platinum, 0.3 tonnes.

33. Figure 7 presents a photo image of mobile phone parts, including screws, washers, buttons, wiring, keys, housing and circuit boards[20]. This figure illustrates the growing complexity of many consumer products. It is reported that 96% of the mobile phone is recyclable and that the current challenge is the recycling of the rubber key pad[21]. However, whether all phone parts should be recycled for their material value or whether some of the non-metallic parts should provide calorific value in the smelting process is the subject of ongoing analysis (see Section 2.3 discussion on eco-efficiency).

[4] Parts per million.

Figure 7: Mobile phone parts – exploded view



2. METHODOLOGIES

34. This case study requires the concurrent use of several methodologies in order to develop a useful analytical framework because "No methodology alone is sufficient to promote more sustainable materials management"[22]. For the purposes of expanding our collective knowledge of SMM, the framework should have three sustainability dimensions: environmental, economic and social. These dimensions are not new for most policy makers. In a number of reports and at several workshops, the OECD Working Group on Waste Prevention and Recycling has examined a variety of study approaches and how they could or should be applied.[23] This section of the report identifies four methodologies that were selected to explore SMM thinking in the context of certain critical metals used in electronic consumer devices: (1) substance flow analysis; (2) life cycle assessment; (3) eco-efficiency and (4) a new proposed framework for incorporated social aspects.

- Substance flow analysis (SFA): Determining appropriate methodologies and assembling useful data is an iterative process; that is, a selected methodology is only of use if there are data with which to work, but in some cases the methodology facilitates collection of the data. Since the stock and flow of materials is essential in understanding SMM, to understand the source and the use of critical metal in the global economy, substance flow analysis (SFA) is employed. Whereas Material Flow Analysis (MFA) considers materials or "goods" comprised of more than one substance, SFA focuses on the stock and flow of something more specific; in this case, a mineral or metal. Since metals are produced and used to deliver specific functionalities, the focus on a product like mobile phones highlights the relationship between various substances and materials. The SFA information can be used to assess the criticality of metals and to identify their geographical origin, their uses and eventually the patterns of their recovery or loss. An illustration of SFA is provided in Section 2.1.
- As noted, mobile phones are comprised of many different substances as shown in Figure 6. As a result, when their end-of-life phase is considered, it makes sense to consider the stock and flow of these products using MFA. That analytical approach can facilitate the collection of data regarding production, wireless subscription patterns, accumulation (hoarding) rates and the flows associated with refurbishing, reuse, recycling and final disposal. Needless to say, the stocks and flows of mobile phones are much different than the stocks and flows of their constituent parts (*i.e.* critical metals).
- Life cycle assessment (LCA): Like all consumer products, mobile phones have a life cycle (and the discussion in Section 3 is organized according to this life cycle). By identifying and understanding what these life cycle stages are, the production, distribution and use of such devices can be established using MFA. The next step is to evaluate the impact of this product and its material components over their entire life cycle using life cycle assessment (LCA), which has been selected as an additional methodology with which to explore SMM. In this case, LCA is used with an environmental weight bias (see Section 2.2).
- Eco-efficiency: The World Business Council for Sustainable Development defines eco-efficiency as "creating more value with less impact" or "doing more with less"[24]. By increasing product or service value, optimizing the use of resources and reducing environmental impact, a business can become more eco-efficient. For the purposes of this case study, the eco-efficiency methodology

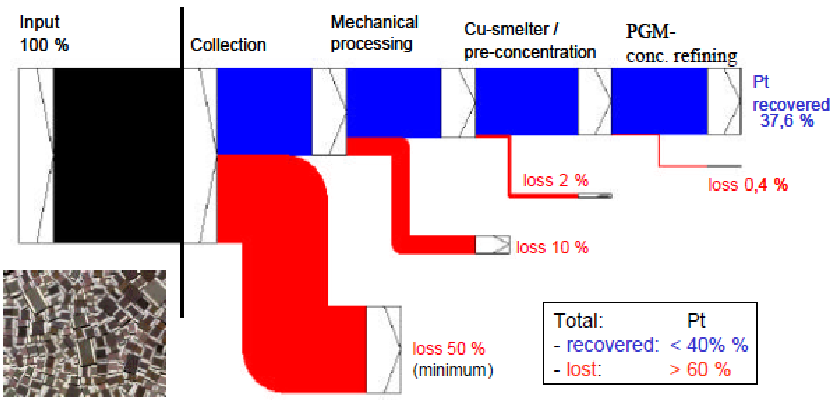
supports the simultaneous consideration of environmental impacts and the costs or benefits of refurbishing/reuse and several other end-of-life options for mobile phones (see Section 2.3).

- Social aspects: Based on the literature review, it would appear that a good yardstick for measuring social impacts does not yet exist. However, the framework discussed in Section 2.4 may help facilitate the integration of social aspects with economic and environmental considerations throughout the life cycle of mobile phones. For the social dimension, the framework developed by Alberto Fonseca and Steven B. Young is included in Annex 12 of document "Critical Metals Case Study Annexes".

2.1. Substance flow analysis

35. Substance flow analysis follows the physical flow of material within a given boundary. Figure 8 illustrates the SFA concept using platinum,[25] and is included here to highlight the complexity of such an analysis.

Figure 8: Generic substance flow analysis for platinum (Pt)



36. The substance flow analysis identifies recycling opportunities and presents the capture rate and the global yield for the different recycling scenarios considered in the case study. The issue concerning stocks and flows of critical metals is something that could be addressed for example by the Center for Industrial Ecology at Yale University.[26] However, it is recognised that the assessment of stocks and flows of substances is still in its infancy: "A satisfactory picture of anthropogenic (in-use) stocks exists for only five metals: aluminum, copper, iron, lead, and zinc".[27]

2.2. Life cycle assessment

37. Life cycle assessment is one of the techniques developed to understand and assess the potential impacts associated with products over an entire life cycle. The LCA technique is standardized by ISO (the International Organization for Standardization) vis-à-vis various guidelines and requirements.[28,29] Figure 9, taken from ISO 14040:2006, presents the four stages of a life cycle assessment.[5]

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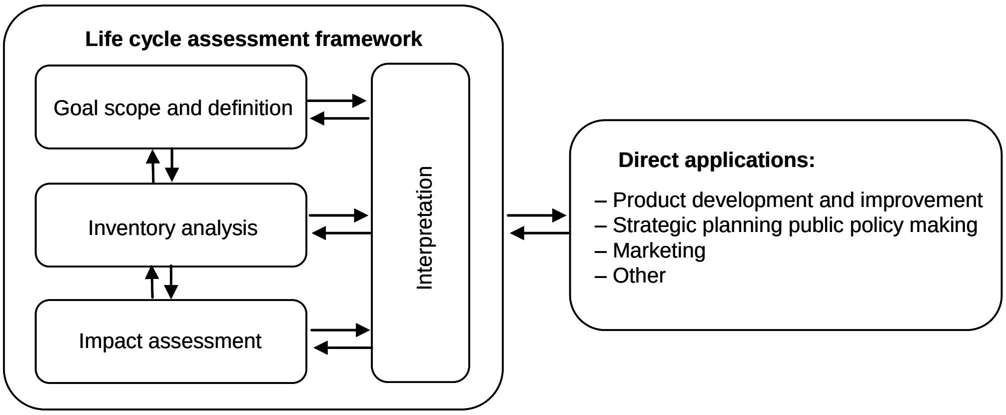
[5] Permission to use the extract from ISO 14040:2006 was provided by Standards Council of Canada, in cooperation with HIS Canada. No further reproduction is permitted without prior written approval from Standards Council of Canada.

Figure 9: Stages of a Life Cycle Assessment Study



38. This study is not a standard LCA because it does not focus on a particular mobile phone model; rather, it uses an average composition based on smelter input average composition of mobile phones.

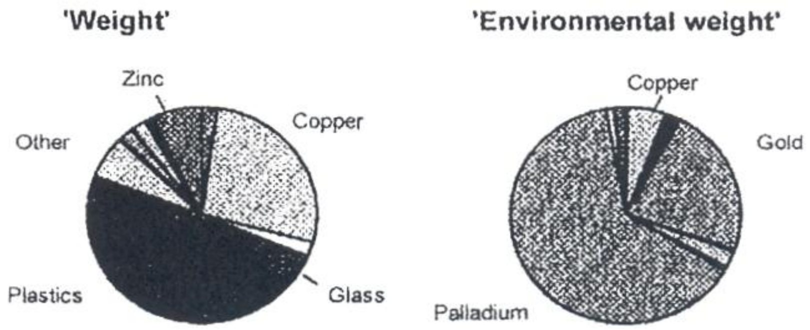
39. The life cycle scope includes the extraction and end-of-life of critical metals. The life cycle inventory (LCI) analysis phase is based on data from the literature. The life cycle impact assessment phase (LCIA) is the third phase of the LCA. There are various methods to model the life cycle impact. In the current study, the modelling of the life cycle inventory uses the climate change factor from the International Panel on Climate Change with a time frame of 500 years and the Cumulative Energy Demand (CED).[6] Other types of life cycle impact models have been developed such as eco-toxicity, human toxicity, and resource depletion but their use requires extensive information that is not always publicly available. Furthermore, those life cycle impact assessment models are less mature and open to some controversy since some of them consolidate several types of impacts into a single score: while multi-impact/single score models appeal to some decision makers, they are not science based and that practice is not recommended by ISO and therefore they are not used in this study.

40. Life cycle interpretation is the final phase of the LCA procedure in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the project goal and scope definition.

41. **Environmental weight** is a composite measure that includes all of the required inputs (material and energy) and resulting outputs (emissions to air, water and land). Whereas the physical weight chart (see Figure 10), is dominated by plastic and copper, the “environmental weight” associated with the production of the mobile phone indicates that some of the important metals (palladium and gold) are much “heavier” in terms of their impacts.[30] From an *environmental perspective only*, it would be more beneficial to recover the copper, palladium and gold from mobile phones and ignore the plastics, iron and aluminum.

[6] Cumulative energy demand equals all primary energy required to produce, use, and dispose of a device –transportation included.

Figure 10: Physical versus environmental weight for mobile phones

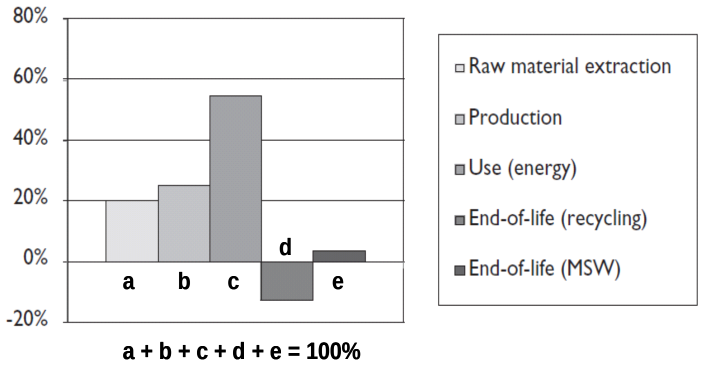


42. The raw material extraction, the production, use of many products and disposal in municipal solid waste (MSW) has net negative environmental impacts (a, b, c and e in Figure 11).[31] In Figure 11, the environmental impacts are integrated in a single indicator that accounts for different emissions: greenhouse gases and ozone depletion. However, consumer electronics can be recycled at their end-of-life, which may have a positive environmental impact (see Figure 11 'd'). In this case study, a consequential approach was adopted, in which the decision makers focus on end-of-life recycling. In fact, recycling metals generates environmental benefits because it can reduce – though not eliminate – the need for mining and it can also result in considerable energy savings relative to virgin materials production and associated reductions in GHG. This vision is also consistent with the issue of criticality because recycling can help reduce the supply risk.

43. Where the end-of-life product or material is recycled, stage 'd' presents a negative value: the benefit associated with end-of-life recycling is the consequence of the offset in primary production (*e.g.* recycling the platinum in a mobile phone displaces the use of primary platinum). In order to select the best practice for design, production, use and end-of-life product management (including recycling), it is important to prioritize individual materials using environmental impact considerations such as those reflected in Figure 10 and Figure 11.

44. In order to assess the impacts of recycling it is essential to develop two parameter estimates. First, the *collection rate* is a measure of the efficiency of the collection infrastructure and, second, the *metallic yield* is a measure of the efficiency of the metallurgical process to reclaim a metal back to its desired quality. The intrinsic value of a mobile phone (*i.e.* precious metal content) has virtually no influence on what the user does with the device at the end-of-life. Most important, the product of the collection rate and the metallic yield is the quantification of the material loop and is referred to as "the recovery rate."[32]

Figure 11: Cumulative environmental impacts of consumer electronics across the life-cycle

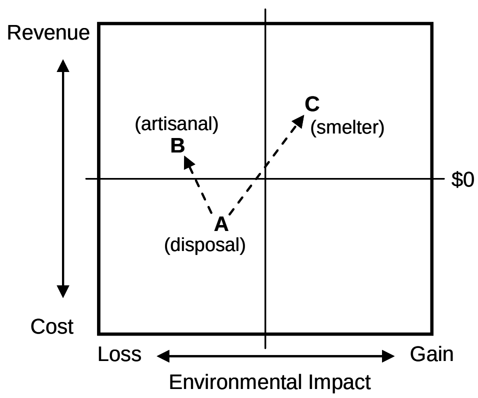


2.3. Eco-efficiency: Combining environmental and economic issues

45. The Quotes for environmentally WEighted RecyclabiliTY and Eco-Efficiency (QWERTY/EE) approach is based on (1) life cycle impact assessment results and (2) economic analysis. It supports the decision making process for post consumer alternatives, either in term of refurbishing/reuse or end-of-life management options. Economic analysis is of critical importance since, traditionally and systematically, it involves an assessment of resource scarcity and optimal use, comparison of potential substitutes, evaluation of opportunity costs, all under given assumptions and constraints. The emergence of corporate social responsibility and extended producer responsibility has led to increased internalization of externalities, which previously were not accounted for.

46. The eco-efficiency calculations of the QWERTY/EE approach[31] can be visualised graphically in Figure 12. The y-axis denotes monetary value. The potential environmental impact is expressed on the x-axis and is either the GHGs (carbon dioxide equivalents) or the cumulative energy demand (joules) for different end-of-life scenarios of which there are three: Scenario A – disposal occurs at some cost with some environmental impact (*i.e.* nothing is recovered); Scenario B – collected items are processed by informal recyclers where some revenues are earned but there are metal losses as well as process emissions; Scenario C – collected items go to a high efficiency smelter where metal recovery and revenue are maximized and environmental impacts are minimized. The optimum situation is located in the upper right corner (Scenario C). Where recycling offsets the primary production of metals, net positive impact can be demonstrated to the extent possible.

Figure 12: Generic eco-efficiency per kg for various end-of-life mobile phones scenarios



47. More emissions usually occur at the manufacturing stage than during the stage in which raw materials are acquired. This is particularly the case for mobile phones (and similar electronic devices) since the miniaturization and the computer power required to carry their increased functionality means that, "kilo per kilo", the energy inputs are more intensive than mining activities.

48. The eco-efficiency approach can also be applied to the reuse/refurbishing stage and to demonstrate the cost/benefits of that activity. In effect, with the QWERTY/EE approach, the best solution is not to improve the level of recycling on a physical weight basis, but to reduce the environmental impact while simultaneously considering the monetary costs.

2.4. Framework for incorporating social aspects

49. Andreas Jørgensen and others[33] recently compared fourteen methodologies and "found a multitude of different approaches with regards to nearly all steps in the Social LCA (SLCA) methodology, reflecting that this is a very new and immature field of LCA."

50. The proposed framework developed by Centre for Environment and Business, Faculty of Environment, University of Waterloo[34] correlates the main life cycle stages of metals used in electronics with 26 social indicators arranged according to four stakeholder groups. The framework includes design, extraction and processing, manufacturing, use, trade, reuse, recycling and disposal. The categorization of impacted stakeholder groups and social indicators was, in turn, based on the most commonly found approaches in the aforementioned methodologies of SLCA. Selected stakeholder groups encompass workforce, users, local community and society.

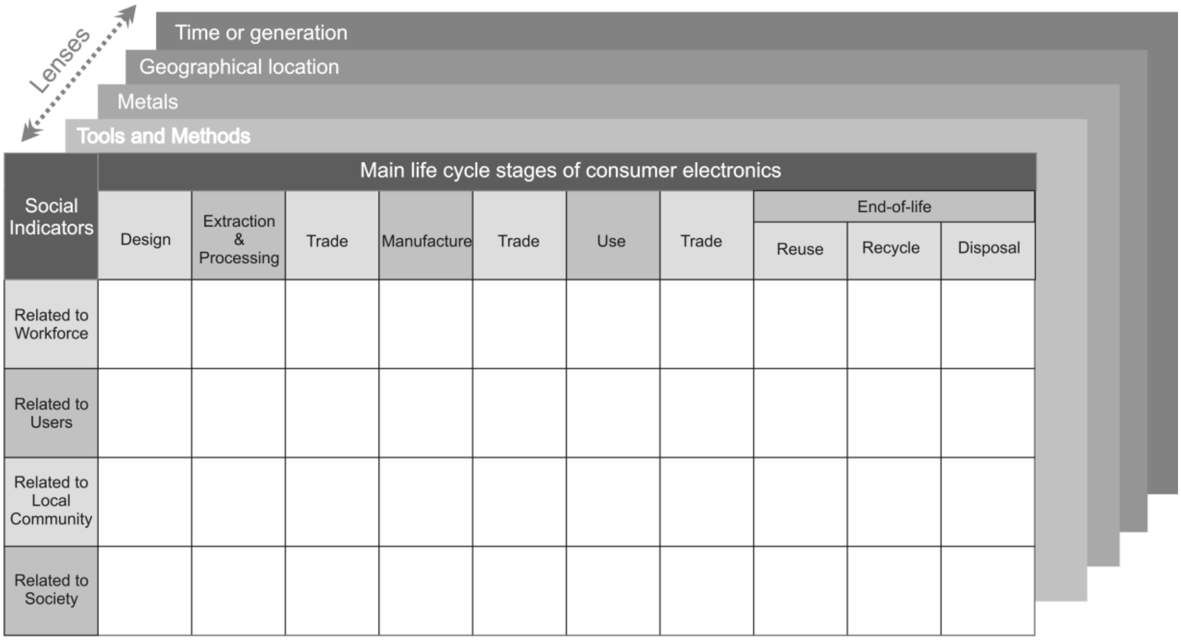
51. The purpose of the framework is first to help build a qualitative understanding of the most relevant social issues across the life cycle of metals used in electronics; and second to relate those issues to tools, geographical regions, specific metals, institutions, time, etc. For the second purpose, it adopts a lenses approach.[35] Through this approach, the scope of the qualitative understanding of social issues can logically be expanded to include:

- tools that can be applied in the management of social aspects;
- institutions and organizations;
- sensitive geographical regions;
- changes over time; and,
- metals of concern.

52. The framework presented in Figure 13 provides the "big picture" related to the incorporation of social aspects in sustainable metals management. It can help identify relevant social problems, knowledge gaps, critical metals, sensitive areas, and opportunities for collaborations among institutions. It can also help to promote the integration of actions across the life cycle, which is a key requirement of the SMM concept. Public or private organizations are likely to find the framework useful as a "first step", before more quantitative and focused actions are taken. The qualitative and exploratory nature of the framework is consistent with the rather embryonic nature of the studies related to the incorporation of social aspects in SMM.

53. As opposed to SLCAs, the proposed framework does not aim at "assessing" social impacts or evaluating trade-offs among life cycle stages or with other environmental and economic issues. It makes no requirements regarding the quantification, normalization or valuation of social aspects. More discussion is provided in Annex 12 of document "Critical Metals Case Study Annexes", including a literature review of related topics.

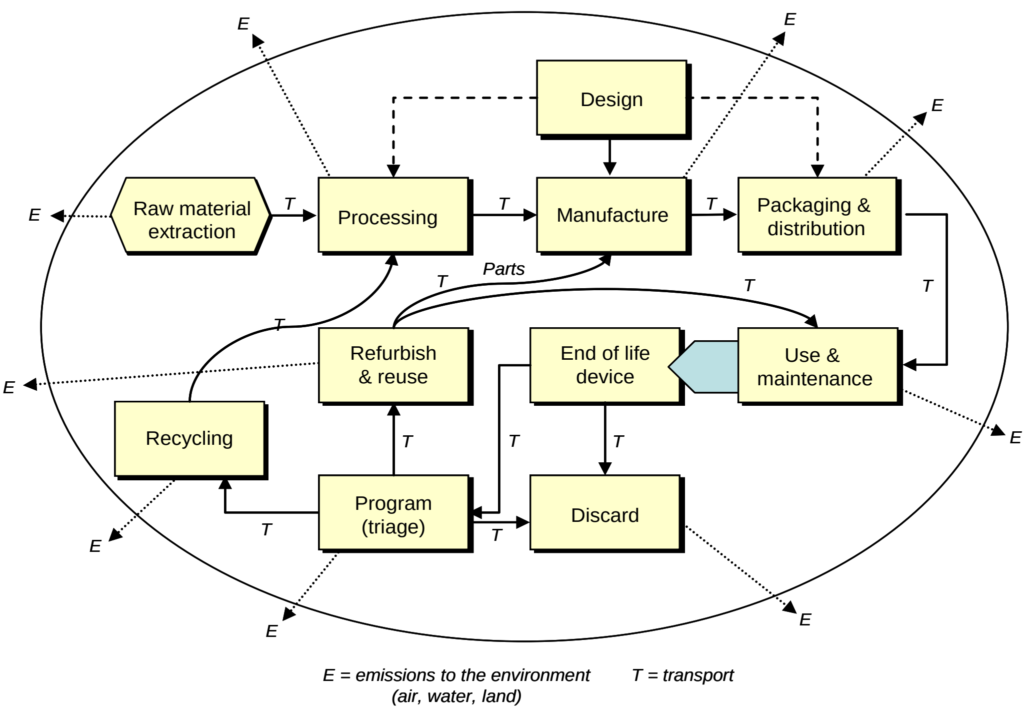
Figure 13: Proposed framework for the identification of social issues (re metals in mobile phones)



3. ANALYSIS AND DISCUSSION

54. Conventional life cycle schematics show the route that materials or products take from "cradle to grave": some refer to this as the "linear economy". However, with the rise of 3Rs (Reduce, Reuse, Recycle) and Extended Producer Responsibility (EPR) thinking, such life cycles now typically include circular paths that either prolong the use of a product (via refurbishment and reuse) and/or feed it back into the production process (recycling). Figure 14 models the flow of mobile phone materials (including critical metals) and parts.

Figure 14: Mobile Phone Lifecycle – Conceptual Material and Product Flows with Associated Emission and Transport Impacts



55. This section of the report is organized to reflect the life cycle of a mobile phone where the use of critical metals is concerned, beginning with extraction and ending with recycling or disposal. At each life cycle stage, the most relevant issues are identified and summarised so that an assessment of the economic, environmental and social dimensions can be explored using the methodologies presented in the previous sections. An important part of this analysis and discussion is the recognition of key information gaps, summarised for each stage of the life cycle.

56. Figure 14 also shows the paths or flows that could be measured as well as where the opportunities for policy (fiscal, regulatory) intervention may lie. From an SMM perspective, therefore, mobile phones are of interest because of their constituents such as critical metals and what happens to them when the devices expire. In this regard mobile phones are intended to represent all consumer electronic

products containing a printed circuit board. Where data are available, SFA and LCA can be used to analyse the economic and environmental benefits (or costs) of refurbishing/reuse and recycling.

3.1. Raw material extraction and processing

57. Where critical metals are concerned, this stage in the life cycle of mobile phones involves first mining and second processing of the ores into material stock ready for manufacture into products.

3.1.1. Points of interest

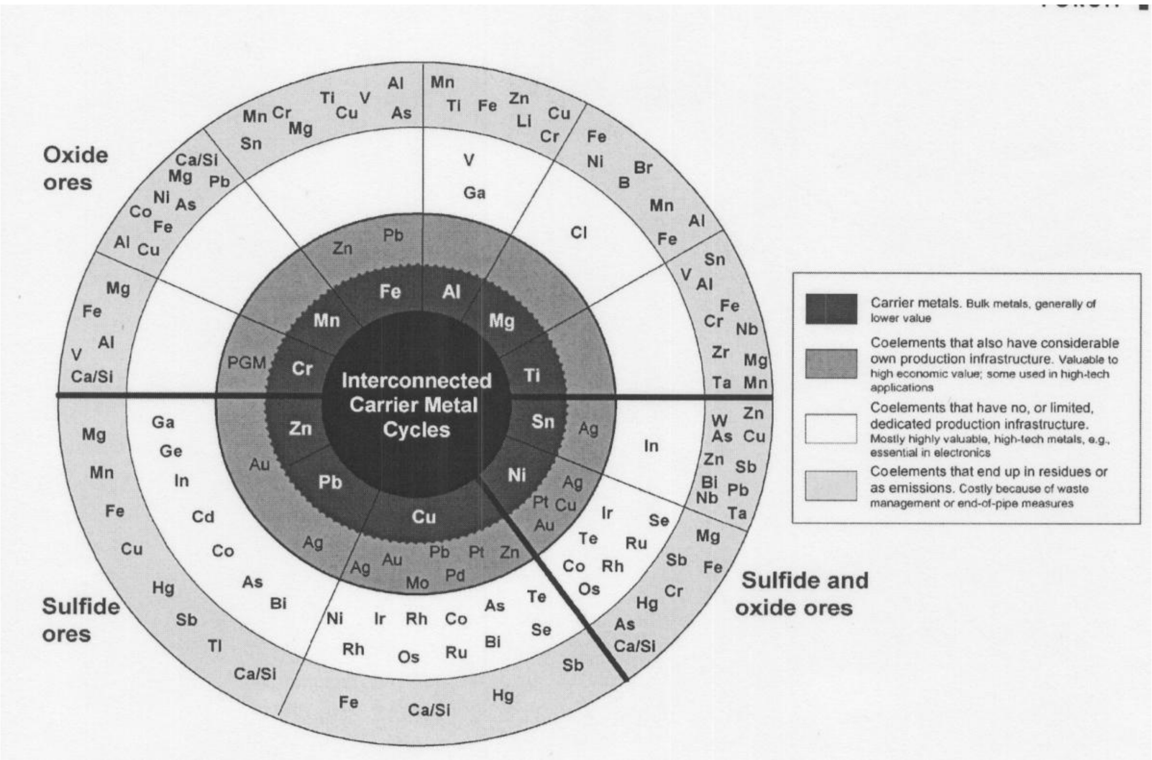
Supply constraints

58. As illustrated in Figure 4 and Table 1, the availability of critical metals may be constrained by their geographical distribution. Generally speaking, when the demand increases more than the supply and prices are high, mining and metal companies will have the incentive to expand reserves and put new primary production on stream: this is a markets driven activity and a metal – once considered critical (recall the coltan example in Section 1) – can quickly become less so when either new supply is found or material substitution occurs. The supply constraints can also be reduced through increased recycling activities.

Co-dependencies

59. Mining and metal production are usually complex systems. Ore usually contains several metals that can be economically produced. The "metal wheel"[36] in Figure 15 illustrates, for example, the natural linkage of the base metals zinc (Zn) and lead (Pb) ore with the occurrence of gold (Au) and silver (Ag). Zinc and lead production is also associated with metals that are of interest for the electronic industry such as bismuth (Bi), cadmium (Cd), indium (In), cobalt (Co), and germanium (Ge). Antimony (Sb) is produced either from antimony minerals with negligible concentration of metals or as a co-product of copper, lead or silver. Beryllium is extracted from simple deposits. Platinum (Pt) and palladium (Pd) usually occur together: their source is ore containing mainly PGMs or but they may also be co-products of copper or nickel.[7] These co-dependencies are such that the production of minor metals (the white ring within the Metal Wheel) cannot respond to a price increase because their production is constrained by a base metal.

Figure 15: The Metal Wheel showing linkage in Natural Resources Processing



60. Furthermore, the existence of co-dependencies illustrates the importance of a system approach. For example lead-tin alloys are used in solder in the electronic industry. In 2002, the use of tin-lead solder in the electronic industry was about 90 kilo tonnes per year.[37] Due to environmental concerns, the use of lead has – in some countries – been banned in applications such as paint, ink, gasoline and solder in electronic and electrical equipment as regulated under in the European Restriction on Hazardous Substances (RoHS) Directive. Where tin-lead solder is concerned (60% tin plus 40% lead), one possible alternative includes the following alloys (by weight): 95% tin, 4% silver plus 1% copper; and 93% tin, 4% bismuth, 2 % silver, 0.5 % copper plus 0.1% germanium.

61. According to the USGS, the 2002 world mine production included 291 mega tonnes of lead and 4 kilo tonnes of bismuth. As most electronic solder is not recycled, it is assumed that 100 percent will be replaced by primary production. According to Graedel[38] the replacement of 90 kilo tonnes per year of lead in tin-lead solder will require 5.4 kilo tonnes per year of bismuth in the tin, bismuth, silver, copper, germanium alloy. This quantity is more than the current annual production of bismuth, which is mainly a co-product of lead production. As a result, the use of bismuth in solder can only be a niche market and not a universal alternative.

62. On the other hand, completely banning the use of lead will affect the supply of several metals used in the electronic industry (see the white circle in Figure 15). In effect, decisions on base metals production can have unintended consequences on minor metals, including critical ones.

3.1.2. Implications

Economic dimension

63. Further to the discussion in Section 1, a few companies dominate word production of selected critical metals. Table 2 provides a summary of the metals with an indication of which mining companies maintain a controlling position, where they are located and what are their percent shares of world production (note that ranges are used to reflect variability based on the two references used).[14, 39]

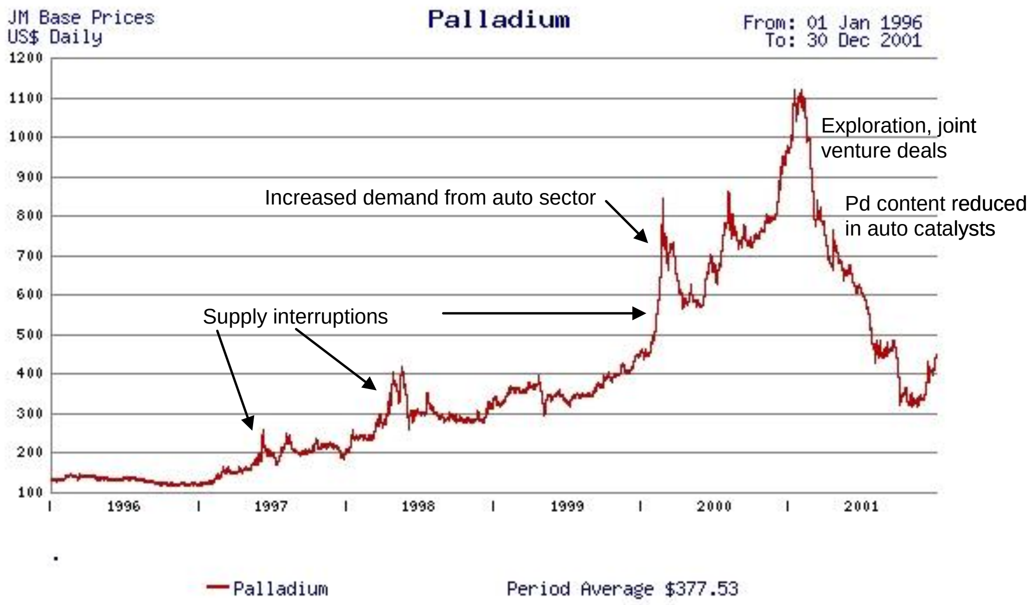
Table 2: Industry Control of Selected Substances

Critical metals found in mobile phones	Share of world production	Country	Mining company, (mine)
Antimony (Sb)	82-87%	China	Hsikwangshan Twinkling Star, (Hsikwangshan)
Beryllium (Be)	81-90%	United States	Brush Wellman, (Delta)
Palladium (Pd)	45-65%	Russia	Norilsk, (Norilsk)
Platinum (Pt)	77-80%	South Africa	Amplats – Implats – Lonnin, (Bushveld)
Other metals			
Lithium (Li)	60-80%	Chile	Sociedad Quimica y Minera de chile SA – Soquimich- (Salar d'Atacama)
Niobium (Nb)	90%	Brazil	Companhia Brasileira de Metallurgia e mineraçao CBMM, (Araxa)
Rare earth elements (REE)	85-95%	China	Baotou Iron & Steel Company, (Bayan Obo)
Tantalum (Ta)	60-70%	Australia	Sons of Gwalia, (Woogina)
Tungsten (W)	75-84%	China	Jianxi Tungsten, (Minnetals)

64. Such high concentrations of supply capacity raise the possibility of short term monopolistic behaviour with potential impacts on supply and price. As discussed in Section 1.32., the African coltan supply restriction event had a direct impact on price. It also led to material substitution and the development of new mines that also affected price.

65. In Figure 16,[40] the price of palladium is tracked over a 6 year period to illustrate the following observation: "The price of palladium increased sharply in the first 5 months of 1998 as delays of shipments from Russia caused increasing physical shortages. The price of palladium rose from a low of $201 per ounce in January to $390 in April. Prices moderated somewhat in early May but surged again in the middle of May, reaching a record high of $417 on May 18. As Russian exports resumed, prices retreated, and trading was in the $205- to $338-per ounce range for the remainder of the year. Palladium averaged $290 per ounce in 1998 compared with $184 in 1997."[41]

Figure 16: Prices for Palladium, 1996-2001



66. Palladium is used in diverse applications in the electronic sector (mobile phones and computers) and in terms of quantity, the multilayered ceramic capacitor (MLCC) is very important.[42] In response to the price increase of palladium in 1998, the market response was to develop alternatives (nickel-based capacitor), further miniaturization and thinner electrode layers. Also note that in 2001 manufacturers of auto catalysts and electronic components responded to the high cost of Pd by reducing its intensity of use (see Figure 16).

Environmental dimension

67. Critical metals are often co-produced with a base metal as depicted in Figure 15 (the "Metal Wheel"). In terms of assessing the environmental impact, the smelter facility is typically assumed to act like a black box; that is, the metal concentrates go in, are processed, emissions are generated, and a variety of metals produced. Since emissions are monitored at the facility level, it is feasible to measure smelter emissions at the sub-system level and allocate them to each co-product but the operational characteristics of these sub-systems are confidential. Therefore, the allocation of the environmental burden associated with the co-production of several metals is usually based on the economic analysis in which the market value of the metal produced is combined with its relative weight (see Annex 8 of document "Critical Metals Case Study Annexes").

Social dimension

68. Many publications, mostly published by NGO organizations, were found to address social issues of concern in the extraction and processing of minerals and metals.[43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53] Those issues were related to almost every indicator of the framework, with the exception of those related to consumers. The publications have diverse purposes and scopes: some address the problems of specific minerals, such as the conflicts related to coltan mineral (tantalum) mining[50] or the bad performance of specific metal companies.[49] Overall, the publications suggest that the impacts on the workforce and on local communities hosting mining operations deserve special attention in policy-making: in this regard, corporate social responsibility initiatives in both the public and private sectors have made enormous in-roads.[54]

If the environmental and social costs of mineral extraction and refining are properly priced through taxes, market instruments or regulations, then markets will lead to the socially optimal use of that resource or material.

3.1.3. Key information gaps

69. As discussed in the environmental dimension section, for the production of critical metals that are produced from a few sites, LCA data are sparse. An enhanced understanding of how the "black box" functions would facilitate the allocation of emissions among the co-products based on their physical interrelationships. In regard to the GHG and cumulative energy demand, no life cycle inventory data are available for antimony, beryllium or tantalum from *ecoinvent*, which is a primary source of information (see Annex 8 of document "Critical Metals Case Study Annexes").

3.1.4. Policy considerations

70. The extractive and processing stages of the life cycle are already covered by an array of policies and regulations that focus on emissions reduction from large industrial emitters. These policies occur at both national (*e.g.* Canada's Regulatory Framework for Air Emissions) and international levels (*e.g.* United Nations Framework Convention on Climate Change (UNFCCC), UN Economic Commission for Europe Convention on the Long-range Transboundary Air Pollution of Air Pollutants (LRTAP) with varying degrees of success.

71. The use of recyclable materials instead of primary inputs is dictated by the market, material specifications, the availability and effectiveness of collection infrastructure, and performance standards. Where metals are concerned, recycled content is not relevant, as discussed in Section 3.2.1. The benefit of recycled metal as feedstock is that much less energy is required to process the material, and when the marketplace is cognisant of this fact, a natural tendency towards increased efficiencies ensues. Public policy could support this propensity through outreach and education activities.

72. Insofar as the development and use of mineral and metal resources is concerned, government policy may not be prescient or swift enough to anticipate rapid technological or marketplace changes, though policy guidelines or principles may help industry reduce or even eliminate externalized costs that may otherwise occur in the environmental or social dimension.

3.2. Design

73. Where the goals of sustainability and resource efficiency are concerned, the design stage of a mobile phone (as with any other consumer product[55]) is of particular interest and may well represent the most fertile grounds for policy use and success. Considerable work is being undertaken in the area of life cycle design that could help inform an evaluation of SMM.[56]

3.2.1. Points of interest

Material substitution

74. As technology evolves to meet or create market demand, product engineers test various metals and materials under exacting performance specifications. The material content of mobile phones is constantly changing and/or could be regulated and these variables influence the selection of end-of-life management options. The designer should therefore consider the criticality of new or alternative materials. For some metals, a sudden increase in demand can provoke a bottleneck in the supply. However, from a policy perspective, it has been noted that the effectiveness of fiscal instruments (such as taxes) intending to

influence material substitution (by making critical metals more costly, for example) may not have the desired effect.[57]

Design for environment

75. In a perfect world, product designers would consult with recyclers since a product that is designed to be recycled reduces end-of-life management costs. With the rise of voluntary and mandated Extended Producer Responsibility (EPR) and stewardship activities in various OECD member countries, progressive brand owners are taking the high (*i.e.* green) road. Since a significant resource investment is associated with the manufacture of mobile phones, the refurbishment of mobile phones for resale or the reuse of sound components would maximize associated environmental and economic benefits. Further, refurbishment should occur rapidly because hoarding of old phones decreases the financial viability of this activity. The cost-effective disassembly of spent consumer electronic devices is a critical step for refurbishment operations where the goal is to maximize the reuse of parts.

76. For the purposes of recycling, the process is manual, mechanical or more typically a combination of both. Although mobile phones contain highly valued metals (in relatively small amounts), only 2.5% of them or one kilo per tonne is captured at their end-of-life.[58] Therefore, unless capture rates can be substantially increased, an alternative design for environment strategy would be to replace energy-intense metals with metals or materials that are more common.

77. Some policy initiatives have mandated the recyclable content of materials or products (*e.g.* newspaper) in order to develop markets for recyclable materials. For metals, it is important to note that grade is determined by conformity to established specifications.[59] The technical criterion for the functionality of the material is the grade, not the recycled content. The recycled content (whether primary or recycled) in specific material feedstock is driven by availability and economics. As a result, it is not relevant to calculate the recycled content of metal feed. A proper approach used by some mobile phone manufacturers is to reduce the quantity of metals (including Be and Sb) and non-metals (such as chlorine and bromide) that can reduce the recyclability of mobile phone by increasing the hazard. If mobile phones were shredded at any stage of the recycling process, the dispersion of beryllium alloy dust would present a significant health concern vis-à-vis berylliosis.[60]

3.2.2. Implications

Economic dimension

78. In the mobile phone, the mechanical components are mostly polymer-based whereas the electrical and electronic components are mainly metallic. The introduction, substitution and use of new materials must balance the need for functionality with cost. However, material composition of mobile phones strongly influences the profitability of the associated recycling sector. For example, the presence of chlorine and bromide in the plastic is a barrier to the environmentally sound management of mobile phones because those elements are a precursor in the generation of dioxins and furans during uncontrolled combustion (*i.e.* open burning). Removal of these elements will reduce health impacts due to informal recycling and may enable "lower tech" smelters to recover more materials. Although "high tech" smelters control dioxin and furan emissions, phone manufacturers are removing the precursors of these releases from their products.

79. While the metal values are volatile, they are mainly high relative to other materials. In any case, it is the metallic content that carries most of the residual value for mobile phone recyclers. Therefore, decisions made during the design stage can have a profound impact on the economic footprint of the device across its life cycle. While higher value metals will attract greater interest from recyclers

(and lower value ones will not), this does not mean that the path forward is lined with greater concentrations of gold or platinum because both collection and recycling processes are not completely efficient.

80. The design stage plays an essential role in sustainable materials management. The composition of mobile phones can have impacts at various stages of its life cycle. As discussed previously, tantalum is essential in the composition of high quality capacitors. When the capacity for production of tantalum was restricted, the price of tantalum increased and substitution occurred. New types of capacitors based on ceramic or aluminum were developed for less demanding applications. And thus, proper design can reduce the criticality of a metal by reducing its demand or its relative importance within the application.

Environmental dimension

81. Beryllium is used in mobile phones in the form of copper-beryllium alloy. Since beryllium is very toxic where exposure is high, the presence of beryllium hampers recyclability. Secondary copper smelters have to establish feedstock control and implement emission control systems. Some mobile phone manufacturers have voluntarily changed their design specification by eliminating the use of beryllium. This is additional proof that design decisions have a ripple effect across the life cycle of a product.

Social dimension

82. A literature review of metal's life cycle and its social ramifications suggest that there is a broad number of "indicators" to consider, including those that impact society, the workforce, users and local communities. With respect to the design stage, factors to be considered include "quality of product or service" (to users), as well as "prevention of unjustifiable risk" (to society). The material and metal selection decisions made by electronic companies can lead to unjustifiable risks to society, wherever these materials result in serious health problems especially for workers in the informal recycling sector. Life cycle thinking in the design stage can improve the reuse of electronic material (and create "green" jobs), improve recycling efficiencies and reduce exposure to workers.[61] Two policy opportunities emerge in order to manage risk: raise awareness and set recycling standards.

3.2.3. Key information gaps

83. Data regarding the changing composition of mobile phones have been gathered and are presented in Annex 13 of document "Critical Metals Case Study Annexes". Design decisions affect all stages in the life cycle and therefore must be carefully considered. Only the manufacturer can assess the effect of the design on the use phase, which is the dominant phase in term of overall impact of mobile phones.[62] Further investigation to determine how strong the link is between "design for recycling", refurbishment and reuse, and the economic benefits associated with increased access to cost-effective telecommunications technology in developing countries would be interesting but is beyond the scope of this case study.

3.2.4. Policy considerations

84. Governments work with a range of regulatory and voluntary policy instruments to reduce or eliminate the use of certain materials that pose risks to human health or the environment at different stages of the life cycle, including ensuring their sustainable use. For example, the Government of Canada's Toxic Substances Management Policy recognizes that while "naturally occurring substances, such as minerals and metals, cannot be virtually eliminated from the environment … there are instances where certain products containing minerals and metals, or their uses, because of the associated risks, may be candidates for bans, phase-outs or virtual elimination of releases from specific anthropogenic sources."[63]

85. As is already occurring in various OECD countries, EPR policies can establish “duty of care” regimes in which manufacturers have an incentive to design their consumer products in such a way that recycling them at their end-of-life can be achieved in a cost-effective manner. However, the influence of EPR on Design for Environment is still debated.[64, 65] This has led some to believe that IPR (Individual Producer Responsibility) may stimulate a stronger and more effective link between the design and end-of-life stages because it takes better advantage of the market place’s competitive nature.[66]

86. The Canadian province of British Columbia has a comprehensive EPR regulatory framework that seeks to encourage design for the environment initiatives in the private sector. A 2009 evaluation of their effort includes an assessment of Japan’s Top Runner Program; the activities of Minnesota’s Pollution Control Agency; the European Union’s Energy Using Products Directive; U.S. Executive Order 13423: Federal Acquisition Regulation tied to the Electronic Product Environmental Assessment Tool; and the Australian State of Victoria’s Design for Sustainability program.[67] Findings and recommendations from the referenced study may be helpful in guiding further exploration of SMM opportunities.

87. Supply chain management is something business does to support strategic objectives, maximize competitiveness, comply with government regulations or respond to customer feedback. A number of large companies have established green profiles by pushing environmental and social principles up their value chains with one of the most notable and recent examples being Wal-Mart.[68] When a major retailer demands that product suppliers meet their purchasing requirements, government policy becomes a smaller (less influential) driver than the marketplace. In fact, mobile phone manufacturers are already responding to green demand by developing eco-friendly devices that include solar or wind-up power sources and recycled or even wood (bamboo) housing.[69] Further life cycle analysis work is required to properly evaluate the use of these alternative or “green” materials.

3.3. Manufacturing

88. Manufacturing is where parts are fabricated from various material inputs according to specifications established during the design stage. How devices like mobile phones are made, has a direct impact on the ease or difficulty of recycling at their end-of-life, which in turn affects costs over the life cycle.

3.3.1 Points of interest

89. In the context of mobile phones and their life cycle, while reuse may displace some manufacturing activities, the disposal or recycling of products or parts will not have the same impact. Manufacturing with critical metal inputs is based on the metal grade and not on the source of the feedstock.

3.3.2 Implications

Economic dimension

90. The international market for handsets is supplied by a limited number of global firms. Nokia is the leader with more than 39 percent of the global market for mobile phones. Samsung follows with 16 percent, while Motorola and LG each have 8.4 percent of the market.[70] With a total market estimated at US$742.2 billion in 2008, mobile services account for 54% of the telecom services market and single handily delivers all of that sector’s growth. While the annual growth rate for mobile services has dropped from more than 12% in 2007 to 8% in 2008, the mobile customer base worldwide grew by another 17% in 2008, which would suggest that post-recession growth potential is solid.

Environmental dimension

91. The manufacturing of components such as printed wiring boards, semiconductors and liquid crystal displays is energy intensive and requires the use of materials with hazardous properties. This stage can be used as a baseline to quantify the benefits of refurbishment and reuse.

Social dimension

92. Numerous publications were found to address social issues in the manufacturing of electronic products in general. The majority of these discussed labour-related problems/indicators.[71,72,73,74,75,76,77,78,79,80,81] A few publications addressed indicators in connection with local communities[77,82,83] or with society in general.[52,77,84,85] The review makes clear the existence of significant labour-related concerns in the manufacturing of electronics, especially in Asia and developing countries.

93. It could be argued that the social dimension of manufacturing is something that is (or should be) addressed domestically through national, regional and local political processes. In a perfect world, the output from these activities is then reflected in national policies, labour laws and other associated legal frameworks. On a global level, and perhaps to address the level playing field issue (among many others), there are organizations like the International Labour Organization that are probably better positioned and better qualified to affect change using approaches that are more relevant and more direct than SMM.[86] In addition, there are other efforts underway that promote and even certify corporate social responsibility at various points along the value chain (*e.g.* Social Accountability International, Global Reporting Initiative, CSR Europe and the Business Social Compliance Initiative).[87]

94. Consumers International (CI) is an independent non-profit group with over 220 member organizations in 115 countries. CI is working with the Ethical Consumer Research Association (ECRA) to identify unethical behaviour where it emerges in industry sectors that produce consumer goods. As a result, CI has published a fact sheet on their web site entitled “The Hidden Cost of Mobile Phones” in which they evaluate 13 mobile phone manufacturers according to environmental and people criteria including (for the latter) human rights, workers’ rights and supply chain policy.[88]

3.3.3. Key information gaps

95. Where the environmental dimension is concerned, the energy required for the manufacturing of mobile phones and the associated GHG emissions have been measured. In the Nokia report,[62] the life cycle impacts of natural resources extraction/refining and manufacturing stages are combined. To fill the information gap will require access to disaggregated values, i.e. the GHG emissions and cumulative energy at the manufacturing/refining stage and at the manufacturing stage. To fill that gap may prove difficult. The work undertaken to develop the fact sheet on the “hidden cost” of mobile phones is not presented on the CI web site: direct contact with the authors of this evaluation may result in a better understanding of how this project was conducted (*i.e.* who made the evaluations and how were they done?).

3.3.4. Policy considerations

96. The European Integrated Product Policy (IPP) initiative focuses on the environmental implications of the product stage while taking into consideration all stages of the life cycle. This policy employs or encourages the use of a number of tools such as LCA, material flow management, eco-design, eco-labelling, process chain management and green procurement (etc.) some of which fall under the SMM umbrella as well. Essentially, the development of a product that is environmentally innovative would likely receive an IPP stamp of approval, if one existed. In fact, research in Germany has confirmed that there is a

positive correlation between certified ESM[7] and environmental product innovations.[89] This would suggest that public policy to support the former would result in generation of the latter. The certification of ESM has taken many forms including the Certified Electronics Recycler[90] (at the International Association of Electronics Recyclers or IAER) and the Recycling Vendor Qualification Program[91] (at Electronics Product Stewardship Canada). These certification initiatives have occurred as a result of productive government-industry engagement, which in itself is good SMM policy. It would be worthwhile establishing an internationally acceptable definition of ESM since interpretations may vary around the world: claims regarding environmental performance, for example, should be transparent and verifiable.

3.4. Product use

3.4.1. Points of interest

97. During product use, there are no direct metallic emissions from a mobile phone; however, the use of energy at this stage (to operate and maintain the mobile phone) is significant.

3.4.2. Implications

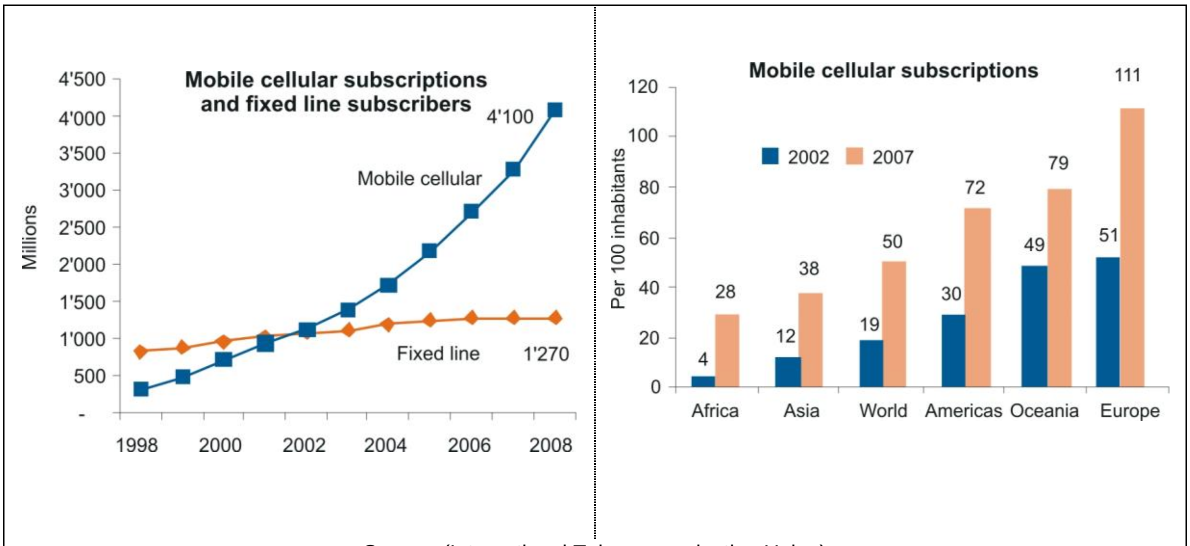
Economic dimension

98. The economic implications of mobile phone use are assumed by the user including (a) initial purchase of the device, (b) subscription with a wireless service provider and (c) the cost of recharging the battery. Revenues to both the manufacturer and the service provider exceed all production and infrastructure costs

99. From a business or technology perspective, mobile phones are an outstanding success story. In 2008, it is estimated that more than 4.1 billion mobile phones[92] were in service worldwide compared to 1.27 to 1 billion in 2002. Six out of ten people now have access to a mobile phone, which means it is the communication technology of choice, particularly in developing countries. In Eastern and Western Europe, mobile phones have achieved a high level of market penetration with more than 1.2 mobile phones person. In North America and Japan, nine out ten citizens subscribe to a mobile phone service. Much of the future market growth will come from Asian and African markets. Mobile phone networks have blossomed in countries that never had extensive fixed-line networks (see Figure 17). These countries are able to 'leap-frog' into the wireless age, thereby creating new markets for mobile phones.

[7] Environmentally Sound Management

Figure 17: Mobile phone subscriptions, globally and regionally



Source: (International Telecommunication Union)

100. While the worldwide number of mobile phone subscribers has grown exponentially over the last twenty years, their average lifetime has decreased from 3 years in 1991 to 18 months by 2002 and by some estimates the lifespan of mobile phone is even less today.[93] Interestingly, and perhaps most importantly, the technical lifespan of a mobile phone is about ten years.[94] Therefore, promoting mobile phone reuse is a good way of supporting sustainable use of materials; however, some original equipment manufacturers may favour recycling over reuse to ensure data security and to encourage purchase of new products.

Environmental dimension

101. The main input during the use stage of mobile phones is energy. It has been suggested that the cumulative environmental impact of energy consumption during the use stage is greater than the impacts assessed for most of the other life cycle stage.[62] But this impact depends mostly on battery and standby power consumption efficiencies both of which are improving quickly (but are not addressed in this case study).

Social dimension

102. Only two of the many reviewed publications gave attention to social aspects in the use of mobile phones.[95, 96, 97] Particularly relevant is the book of Ling[96] which presents several aspects (mostly positive) associated with the use of mobile phones, reflected in the following three indicators: “improvement of social and economic opportunities”, “quality of product or service”, and “protection of privacy”. The publications also stress mobile phones as a technology that contributes in several ways to national economies.

103. The economic benefits of wireless communication in India, particularly the agriculture and fishing sectors and “LabourNet” for the informal employment sector, are attributed to increased productivity directly facilitated by mobile phones.[98] It is reasonable to assume that similar economic benefits are being experienced in other developing countries.

104. The negative health implications of prolonged mobile phone use have been a source of significant public concern and the focus of several studies with results that may (or may not) help inform the analysis of critical metal use.[99, 100] Given the extent to which mobile phone have become a mainstay of communication globally, the results of ongoing work on these issues should continue to be monitored.

3.4.3. Key information gaps

105. Better data regarding the global flow of new, used and obsolete mobile phones needs to be assembled. This effort can begin with a summary of mobile phone flows in all OECD countries. Do the economic and social benefits of mobile phone use in these and other countries outweigh the environmental impacts of informal recycling or inadequate final disposal practices when these devices are finally discarded?[101] This is a question that cannot be easily answered since the benefits and costs of mobile phone use or recycling/disposal are unevenly distributed across all three sustainable development dimensions, particularly in developing countries.

3.4.4. Policy considerations

106. As noted, there is very little if any impact related to metals during the use phase of the mobile phone. Where overall environmental impact is concerned, the recharging of these devices and the fact that users often leave them plugged in longer than necessary, represents a burden on energy supply systems; however, standards have or are being developed for standby power consumption[102,103,104] while various manufacturers are using a ratings system to inform consumers about the amount of energy consumed in standby mode.[105]

107. The ever-decreasing life span of consumer electronic products like mobile phones is a startling manifestation of premature product obsolescence and new product design driven by brand owner competition that has driven the world economy for generations. In addition, governments that introduce hands-free laws regarding mobile phone use in vehicles may also provoke premature redundancies.[106] Government influence in this regard may be limited to green procurement practices (and showing the "way forward"). In other words, when governments purchase or lease equipment, contracts could specify product durability requirements or, more effectively, government policy could simply increase the time such devices are in use. In fact, the leasing of mobile phones by individual consumers or institutions might ensure that the vast majority are collected at their end-of-life. Product labelling is another domain that national governments may want to explore to determine if any influence could be brought to bear.

108. There is little doubt that a reversal of this short product lifespan trend would be beneficial from a resource perspective, however, the economic and social impacts are difficult to forecast.

3.5. End-of-life

3.5.1. Points of interest

Program options

109. One of the more critical factors affecting economies of scale for any of the end-of-life scenarios being considered is the existence of a collection program where triage is used to sort mobile phones into reusable and recyclable fractions (and there may be some contaminants to discard at this stage as reflected in Figure 14). Options regarding end-of-life mobile phones are essentially fivefold: product reuse (including refurbishment), component recovery and reuse, material recycling, energy recovery or final disposal. Section 3.6 describes the refurbishment and reuse path (*i.e.* product and component recovery) while Section 3.7 covers the material recycling route. In Section 3.8 energy recovery is briefly addressed with final disposal since this end-of-pipe management option does not directly impact critical metals.

Collection

110. In recent studies, it has been shown that the cost of collecting mobile phones or WEEE[8] is between 80 and 90% of the total recycling cost.[117,118] Without effective collection infrastructure mobile phones would either remain in the user's home or be discarded. Three types of collection programs exist: (1) buy-back, in which mobile phones are purchased from end users (when metal market values are high or when the reuse market is strong); (2) take-back (including mail-in), in which phones are accepted without reimbursement but perhaps with an incentive such as a prepaid envelop (usually from the wireless service provider or the mobile phone manufacturer); and (3) fundraising, in which phones are donated and the proceeds go to a charitable foundation. The flow of collected mobile phones through one channel or the other is currently not known, but better data tracking may coincide with the introduction of regional or national stewardship programs.

Transport

111. After the use phase, the preferred flow of post consumer mobile phones is comprised of (a) product that is intended for refurbishing and reuse and (b) product that will be recycled. Transportation aspects need to be taken into account in order to fully assess the environmental and economic impacts of each of the end-of-life scenarios being considered. Transportation is involved in each of the scenarios; this includes transportation from domestic and commercial sources to collection, consolidation and sorting centers and transfers to reuse, recycling and disposal destinations. In the initial stages, transportation would be by vans and trucks while later stages would involve transporting the mobile phones longer distances by rail and sea. There are both regional and international transportation requirements and regulations to consider.

Material flow

112. One mobile phone manufacturer (Nokia) has conducted a significant amount of research regarding their end-of-life products and a number of reports that they have initiated are provided in the references to this case study.[62, 154] In Annex 5 of document "Critical Metals Case Study Annexes" a schematic is presented by Nokia that conceptualises the global flow of discarded mobile phones.

3.5.2. Implications

Economic dimension

113. Preliminary screening is a critical step since the outcome of it will decide the subsequent end-of-life option for those mobile phones that are collected. At this point much of this sorting is done manually but efforts are underway to automate it, which would greatly reduce this cost. It has been estimated that manual sorting of mobile phones costs US$4.17 per phone while semi-automated sorting costs only US$0.83 per phone.[107] However, if the average wage for a production worker in China and India is about US$1800 per year[108] or US$0.90 per hour, all of a sudden manual sorting only costs 15 cents per phone. Clearly this is another factor that must be taken into account in the overall cost-benefit analysis and therefore having good data is important, especially with respect to how these costs vary globally.

114. Logistics ("having the right thing in the right place at the right time"[109]) typically flows outward from the point of production to the consumer: efficient logistical planning is a profit driven activity. Where the management of end-of-life mobile phones is concerned, the term "reverse logistics"[9] can be

[8] Waste Electrical and Electronic Equipment

[9] Reverse logistics may also be referred to as reverse supply chain or reverse distribution.

used. A definition of reverse logistics is "the process of planning, implementing and controlling flows of raw materials, in-process inventory, and finished goods, from a manufacturing, distribution or use point to a point of recovery or point of proper disposal."[110] However, reverse logistics is probably more challenging than (forward) logistics given the variability and uncertainty of used or retired mobile phones (see Annex 10 of document "Critical Metals Case Study Annexes" for a detailed comparison). A comparison of the cost of making and selling a mobile device versus the cost of collecting it (etc.) may advance this discussion though the former is likely to be proprietary. In any case, if the wireless industry were to assume responsibility for these end-of-life devices via a voluntary EPR (as is happening in Canada – see Annex 11 of document "Critical Metals Case Study Annexes"), then government does not need to know about production/distribution costs.

Environmental dimension

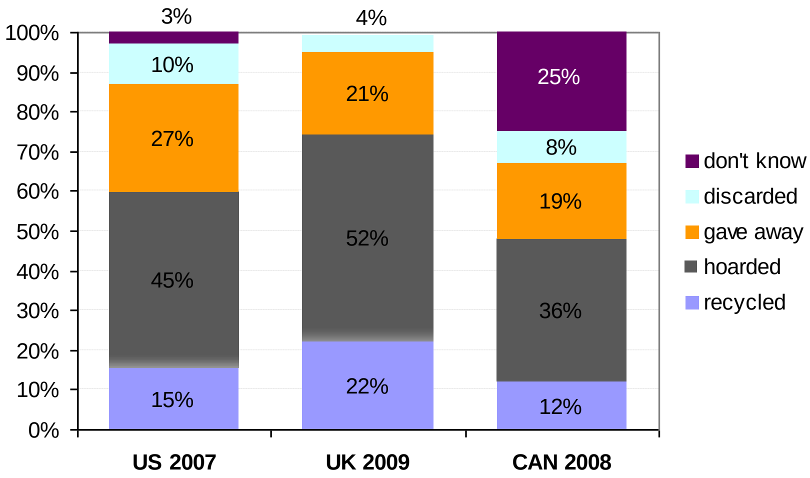
115. The environmental impact of users taking back or mailing in end-of-life mobile phones is hard to measure and therefore is discounted. The behaviour of the user is difficult to model but it is presumed with such a small device that the user will likely multi-task; that is, the user will (can) take back an old phone to the place of purchase in order to buy or lease a new one.

116. By using rail transport instead of trucks, the environmental impact can be reduced by 62-73%, though this might vary with national circumstances.[111] It is important to take into account the environmental impacts of transportation in determining the preferred end-of-life scenario for mobile phones. For example, depending on the distance travelled to pick up the domestic waste, recycling had a net negative environmental impact as a result of the fossil fuels consumed and the production of inorganic matter that can have negative health implications.[112] The quantity of material shipped is directly related to its impact. It is therefore important to identify and assess the modes of transportation (air, land or sea) involved in each end-of-life scenario in order to get a complete picture of its environmental impact.

Social dimension

117. To be successful, the end-of-life program must be easy to implement, accessible and convenient for consumers, and cost-effective to operate. Ultimately the participation of the mobile phone user is of prime importance. Consumer surveys reveal an interesting array of behaviours when it comes to the real or perceived end of a mobile phone's utility. Figure 18 presents the results from three such surveys in Canada,[113] United States[114] and United Kingdom.[115] If the survey findings are combined, it appears that 16% of mobile phones are recycled (following their "first" life), 7% are disposed in the municipal waste system, 45% are hoarded, and 23% are given or sold. The fate is unknown for about 9% of end-of-life mobile phones. Both the final recycling and discard rates will be higher once those stored, lost or sold mobile phones are eventually dealt with.

Figure 18: Mobile Phone User Surveys – 2007 to 2008



3.5.3. Key information gaps

118. In terms of LCA, the question of transport has been extensively modelled. However, the distance travelled by mode of transport needs to be defined. With tonne-kilometre data and the mode of transportation, the potential environmental impact can be calculated with the help of life cycle databases such as *ecoinvent*. More extensive cost data are required to better understand the mobile phone sorting stage, whether manual or semi-automated.

119. The mobile phone fate data shown in Figure 18 are helpful but more investigation is required to determine why consumers hoard mobile phones, for how long and what eventually happens to them. Better understanding of this behaviour will help in the development of targeted programs to collect these items.

3.5.4. Policy considerations

120. Where recovery rates remain low, it is possible that a deposit program for mobile phones would boost their capture (the consumer is charged an additional fee that is fully or partially reimbursed when the phone is returned to either the point of purchase or to some other purpose built depot). Deposits or refunds have been used for a number of different items including beverage containers, cameras, batteries and even car bodies.[116] Typically deposits work best for products that have relatively short life spans or the program becomes difficult to manage. One of the policy elements of deposit schemes to work out is what happens to unredeemed deposits – this could be done by ensuring not-for-profit status through legislation and by considering unredeemed deposits as income that is used to drive down program cost.

121. Deposits or refunds represent an option for both industry stewards and regulators and perhaps are something that an EPR program would introduce if other mechanisms were deemed unsuccessful (as a result of missed recovery targets, for example). Although deposit systems are not supported by manufacturers and retailers alike because the product cost and administrative burden both increase, they may be the best way to engage consumer interest in returning expired mobile phones to collection points.

3.6. Refurbishment and reuse

122. Mobile phones recovered via a collection program and destined for reuse are processed as follows: (1) the devices are screened electronically to assess their functionality; (2) if technically sound, all phone data are erased and the phone may be re-sold as is; (3) if the phone is deemed reparable, it will receive “new” parts and be re-sold, virtually as is; and (4) the phone may be cannibalised for useful parts (for other phones or other consumer electronic devices) and the remainder are destined for recycling (see Section 3.7).

3.6.1. Points of interest

Reuse of mobile phones

123. No accurate numbers are available on the size of the reuse market but for the US, it has been estimated that 50% of refurbished phones go to domestic markets while the rest are exported to overseas markets.[117] The main driver for reuse is economics: with an average profit margin of US$15-21 per phone (revenue minus costs), this is one of the most profitable fates for end-of-life mobile phones.[118] Interestingly, it has been estimated that over 90% of mobile phones resold in the U.S. and Europe have received minimal attention in terms of actual refurbishment.[118]

124. The market for used mobile phones has been steadily increasing in developing countries such as China, India and Nigeria. One factor limiting the number of mobile phones that could be reused is the use of different telecommunication standards in different parts of the world.[10] This technical limitation has caused demand to outstrip supply of used mobile phones in some regions and this impacts price. It is possible that a large number of mobile phones shipped to developing countries for reuse (as claimed on the shipping manifest) are going to informal recyclers instead, but this is unlikely given the fact that a reusable mobile phone is worth more than the material value of its parts.

125. The international trans-boundary movement of used mobile phones has been addressed extensively in the Basel Convention’s Mobile Phone Partnership Initiative (MPPI). The MPPI prepared guidelines for collection and trans-boundary movement of both used and end-of-life phones, and environmentally sound management and recycling (referenced in Section 1.3.4).

Reuse of mobile phone parts

126. In addition to reuse, old mobile phones also have value in the second hand parts market. This market segment is still being developed but it has the potential to grow and this may represent a policy opportunity. A Japanese company has recently announced its intention to use recycled phone parts in the production of digital cameras.[119] In fact, many of the components in mobile phones could find new life in other electronic devices such as toys or calculators. In terms of parts reuse therefore it may be helpful to think in terms of closed loop (parts used in other mobile phones) and an open loop (parts used in other devices).[107] Further research is required to better understand the flows of mobile phone parts though they are subject to typical marketplace forces and are therefore likely difficult to track and subject to rapid change. In Canada, some OEMs allow parts reuse and some do not: this may be the case elsewhere.

[10] There are three global telecommunications standards: time division multiple access (TDMA), code division multiple access (CDMA) and global and system mobile communications (GSM)

3.6.2. Implications

Economic dimension

127. The re-sale price for high-end phones such as Motorola RAZR (2006) can be as high as US$30-40 while most of the low-end models will be worth only a few dollars.[107] In the United States alone, it is estimated that over 100 million handsets will be re-used and by 2012 this activity will generate more than $3 billion in revenues.[120] Undoubtedly, mobile phones recovered in OECD countries that are refurbished and exported to developing countries are less expensive than competing new products. However, it is not clear that mobile phone reuse has much impact on the production of new units.[118]

128. The markets for used parts from mobile phones are at an early stage of development. Most parts have an economic value with distinguishable attributes that could lead to the emergence of more formal, global commodity markets, which could generate important revenue streams similar to the one observed for the re-use of mobile phones. The value of second-hand parts may be influenced by the phone model. Refurbishing companies that work closely with original equipment manufacturers (OEM) can generate a high volume of parts, many of which can be sold into the domestic repair market. OEM specifications may require suppliers to provide brand-specific parts in order to protect their status as an OEM: they may also instruct the recovery agent to destroy/recycle the devices which, as second hand products, compete with their latest models.

Environmental dimension

129. The reuse of a mobile phone essentially extends the use of resources that have already been mined, processed and transformed into the widgets with which consumer electronic products are comprised. It would be useful to know if reuse offsets the purchase of a new mobile phone (with commensurate effects along the value chain), but such displacement rates are currently (2009) unknown.[118] The environmental impact of refurbishing is mainly associated with reverse logistics; that is, transporting them from the first user to the refurbishing facility and then back to the market.

Social dimension

130. No publications addressing social aspects in the reuse of mobile phones were found. It is noteworthy, however, that arguments in two publications[101,121] on the benefits of reusing computers are applicable to mobile phones as well. That is, that the reuse of electronics (thus, mobile phones) can contribute to national economies and to lessening the global digital divide. This echoes observations made in Section 3.4.2. While the prospect of "green" jobs via increased refurbishment and reuse aligns with most OECD member country goals (including support for or training of disadvantaged members of society), such employment opportunities are probably exported with the second hand mobile phones (though there are probably more opportunities with other e-waste).

3.6.3. Key information gaps

131. What are the environmental impacts associated with the activity of refurbishing? How many mobile phones are required to make a refurbished one? What are the costs to refurbish a mobile phone? What are these costs comprised of (labour, equipment, energy, etc.)? What are the product displacement rates as a result of reused phones? If phone reuse ended, would the production of new units need to be ramped up (if so, by how much)?

3.6.4. Policy considerations

132. Based on the 3Rs hierarchy, the refurbishment and reuse of mobile phones is a higher priority than recycling or energy recovery. The energy requirements associated with raw materials processing and manufacturing are indeed greater than those required for refurbishment. However, where displacement is concerned, it could be argued that material (i.e. metal) displacement is higher than product displacement because recycled and primary metals are perfect substitutes for each other whereas a refurbished phone does not have the same value or acceptance as a new device. Therefore, if product displacement is not occurring as a result of reuse, and if the displacement rate of metals recycling is high, then it's possible that where resource efficiencies are concerned, mobile phone recycling is more important than reuse.[122]

133. Regardless, no policy is required to encourage mobile phone reuse since it is happening on its own accord and primarily for economic reasons. In fact, the entire end-of-life triage and reverse logistics for captured mobile phones may be totally financed by the reuse sector and not by the recyclers, where margins have been reduced over the last decade because both phone size and precious metals content have shrunk.[118]

134. If the purpose of government policy is to change behaviour towards a "preferred" state, then every effort should be made to encourage mobile phone users to return their expired devices to any of the myriad collection programs that already exist. Some EPR programs assign the responsibility for public education to the designated industry stewards. In Canada, the CTWA has created a National Cellular Phone Recycling Program in which voluntary stewardship programs are being introduced province by province: in all cases, the wireless industry has identified education and awareness as one of their responsibilities.[123] (See Annex 11 of document "Critical Metals Case Study Annexes" for a life cycle overview of mobile phones in Canada).

3.7. Material recovery and recycling

3.7.1. Points of interest

Interim processing of mobile phones

135. During "program triage," as identified in Figure 14, obsolete mobile phones are collected and sorted into reuse and recycling streams. Mobile phones that can be refurbished and reused are addressed in Section 3.6. Those devices destined for recycling are sent to interim processors where the batteries are removed and the mobile device mechanically disassembled or deconstructed. Reusable parts may also be scavenged at this time. Section 3.7 is about material recovery and the recycling or conversion of metal scrap into new material which, in turn, is sold on to manufacturers to be used in new products.

136. In some interim processing operations, mobile phones or parts therein are shredded to facilitate the separation of metallic from non-metallic materials. Although these plants have air pollution control equipment, some industry experts claim that it would be better to send circuit boards and mobile phones (with batteries removed) directly to an integrated smelter to maximize the recovery of all contained metals.[124] In this regard, it has been proposed that interim processing of electronic devices like mobile phones and motherboards is not required.[31] However, many interim processors can efficiently sort and separate expired mobile phones into various marketable materials. An argument to support shredding is data security (a frequent requirement of the telecommunication companies that collect end-of-life mobile phones) and reduced transport costs (where a box of shredded printed circuit boards is much more economical to ship than non-shredded boards).

137. An interesting point of debate is how to treat the plastic fractions. From an SMM perspective and where plastics are concerned, which is more beneficial: material recycling or thermal recovery?

While this discussion is outside the scope of this particular case study, it is recognized that some interim processors of e-waste may decide, for example, to chop cables to recover the copper while others may send the cable directly to a smelter where the plastics serve as a heat source for the process: this is an economic decision though the smelters will have limits on non-metallic content. The life cycle benefit of one approach over the other likely depends on a variety of conditions that are examined in the SMM plastics case study as well as in other reports.[125] Insofar as mobile phones are concerned, the thermal use of the plastic content to help recover the metals and thereby reduce potential mining impacts is considered a high priority by some[126] and a low priority by others.[127]

Informal and "high tech" material recycling

138. The flow of mobile phones to developing countries for reuse or recycling is largely unknown but it is estimated that only 2.5% of the mobile phones collected go to the five largest high tech pyrometallurgical recycling plants worldwide.[58] It has been found that significant quantities of electronics are being shipped to developing countries, which – although classified as functional – are in fact e-waste for dismantling and processing at informal plants for the recovery of selected metals.[128] The quantity of mobile phones included in these material flows is unknown but likely to be proportionately small by weight.

139. A global list of e-waste recyclers does not yet exist although this is something that the Basel Convention secretariat may want to consider as it advances environmentally sound management (ESM) principles in this area: where are all the ESM facilities located for processing and recycling electronic waste? Once mobile phones are processed they may be sent to one of the five largest integrated pyrometallurgical smelters located throughout the world.[129] Most of these plants have very high environmental standards and may even be ISO 14001 certified: In fact, an internationally recognised certification body may have an important role to play in building ESM capacity around the world (see discussion below). Before any gas leaves the plant, it is passed through heat exchangers to recover the energy and then cleaned using bag house filters, electro filters and scrubbers. Sulphur present in the feed is converted to sulphur dioxide and is captured as sulphuric acid and sold. Final emissions are closely monitored for metals and dioxins and furans. There are other pyrometallurgical smelters around the world that are permitted, licensed or authorised to recycle electronic waste although some of these facilities cannot process materiel that contains plastics or complex devices such as mobile phones. Since stringent emission control technologies are very expensive, only the large integrated facilities with large throughput can afford them.

140. As an example of how an integrated smelter works, the Umicore Process is presented graphically in Annex 6 of document "Critical Metals Case Study Annexes". This process involves the integration of a copper smelter, a lead smelter and an electrowinning operation (hydrometallurgy). Sophisticated control and treatment are required in order to minimise the generation of toxic substances (such as dioxins and furans) and reduce uncontrolled emissions to the environment.

141. The flow sheet of the informal hydrometallurgical process is quite simple. The diagram in Annex 7 of document "Critical Metals Case Study Annexes" for processing of printed circuit boards[134] can apply to mobile phones as well. The heart of the process is the gold extraction process in which the liquid effluents are discharged directly into the environment. Workers are exposed to the gas emissions caused by the open burning of coal and the evaporation of reactive solution. While, some facilities in Southeast Asia claim that they process electronic waste by hydrometallurgy under ESM conditions, reliable data to support these claims was not found. It is likely that only a small percentage of electronic waste (and mobile phones) actually goes to these operations; however, the efficiency of those operations is questionable: at the present time (2009) there are no internationally recognized standards for such operations though the Basel Convention Regional and Coordinating Centres[130] are helping to develop knowledge and capacity in

those parts of the world that require support. As mentioned previously, a comprehensive inventory of all ESM recycling facilities may be a good place to start.

Metallurgical yields

142. The recovery of the various metals is much higher in the smelter operations compared to informal operations. For example the recovery of metals such as copper, palladium, bismuth and gold at one of these plants is greater than 95% at the Umicore Refinery. Surveys of the other integrated smelters should also be performed to determine their environmental performances and metallurgical efficiencies. In comparison, informal operations focus on recovering superficial gold but their yields are typically less than 50%. Surveys of the other high tech plants should also be performed to determine their environmental performances (see Annex 9 of document "Critical Metals Case Study Annexes").

143. There are also a number of hydrometallurgical plants that have been reported in the literature that can process e-waste.[131] These operations consist of a series of acid and caustic leaches that serve to solubilise the metals of interest, which are subsequently recovered in electro refining, reduction or crystallization processes. Unlike pyrometallurgical operations where most of the discharges are solids (slag that has immobilised most of the emissions), hydrometallurgical operations produce their waste in the form of liquids, gases and solids. In both cases, ESM facilities will have the proper emission controls in place.

144. Recycled platinum and palladium accounted for an estimated 14% of total supply in 2007. It is projected that the recycled part of total supply will continue to increase by about 2% per year.[132] Most of the beryllium recycled is "new scrap" that is collected off the manufacturer's floor. When electronic scrap is smelted, the beryllium forms slag and thus is not recovered. Regardless, beryllium is very toxic and recycling may present some challenges in term of safety. Antimony is mainly recovered from lead acid batteries and can be recovered from post consumer mobile phones in a smelter with variable efficiencies.

3.7.2. Implications

Economic dimension

145. Many mobile phones targeted for recycling end up at informal operations in developing countries or at pyrometallurgical processing plants. As mentioned already, the biggest incentive to send phones to developing countries is the lower labour costs. For example, recycling a PC in the U.S. or EU costs about US$30, while in China and other developing countries it costs about US$2:[133] the cost differential for mobile phones may be comparable. However, a more complete analysis of informal recycling versus an integrated pyrometallurgical smelter (after appropriate pre-treatment) suggests that the economic benefit of processing mobile phones through the latter is actually much greater than the former because of the differential recycling yields.

146. Revenue for mobile phone recycling comes from the precious metals that are contained within them, such as palladium and platinum. Since the metal concentrations are very low, these operations have to process large quantities in order to be profitable. In addition, capital-intensive plants rely on very high metal recoveries, typically greater than 90% for several metals. The price of metals fluctuates a great deal and therefore the profitability of these operations is cyclical. In the following short analysis, two approaches to mobile phone recycling are of interest: pyrometallurgy versus informal operations. The relative economics for two different recycling routes of for mobile phones in India can be estimated and compared using the following formula:

Total profit = Sales of Recovered metals – Total Operational Costs – Total transport Costs

147. To assess the economics of recycling Indian consumer electronic devices via the two approaches, the composition of Printed Wiring Boards[134] (Cu 10%, Au 200 parts per million or ppm, Ag 1000 ppm, Pd 100 ppm) and mobile phones[135] (Cu 13%, Au 341 ppm, Ag 3512 ppm, Pd 144 ppm from Figure 6) is considered. Table 3 presents the results of an economic analysis and is based on sales of gold, silver, copper and palladium.[134]

Table 3: Cost/benefit analysis for two recycling scenarios of Printed Wiring Boards (Euros per tonne)

Variables	Informal sector	Pyrometallurgical operation
Sales of recovered metals	1 300	4 600
Transport costs	---	600
Operational costs	800	1 100
Profit	500	2 900

148. For mobile phones, the economics for the recovery of precious metals are more favourable for Printed Circuit Boards when they are processed in a pyrometallurgical facility rather than in the informal recycling sector. Moreover, the possibility of recovering critical metals from end-of-life electronic devices in informal operations is completely absent (and hence the revenue differential presented in Table 3). Transport costs refer to the expense of shipping the spent devices from India to Europe – that is why no transport costs are indicated in the informal sector column.

149. Table 4 illustrates the fact that the immediate financial incentive to recycle e-waste is associated with precious metals.[136] It is further observed that the recycling of mobile phones and several other electronic devices carry the same economic drivers. For example, where 210 ppm of palladium is found in a typical mobile phone (varies slightly from the figure quoted above but falls in the 91-349 ppm range of Pd content in any case), the value of that metal represents 21% of the total value of materials found in the phone.

Table 4: Weight versus value distribution for some consumer electronic devices

Weight	Fe (%)	Al (%)	Cu (%)	Plastics (%)	Ag (ppm)	Au (ppm)	Pd (ppm)
TV-board	28	10	10	28	*280*	*20*	*10*
PC board	7	5	20	23	*1000*	*250*	*10*
Mobile phone	5	1	13	56	*1380*	*350*	*210*
Portable audio	23	1	21	47	*150*	*10*	*4*
DVD player	62	2	5	24	*115*	*15*	*4*
Calculator	4	5	3	61	*260*	*50*	*2*
Value Share	**Fe (%)**	**Al (%)**	**Cu (%)**	**PM sum (%)**	**Ag (%)**	**Au (%)**	**Pd (%)**
TV-board	4	11	42	43	8	27	8
PC board	0	1	14	85	5	65	15
Mobile phone	0	0	7	93	5	67	21
Portable audio	3	1	77	20	4	13	3
DVD player	13	4	36	48	5	37	5
Calculator	0	5	11	84	7	73	4

("PM" is Precious Metals and includes Ag, Au and Pd)

Environmental dimension

150. The informal recycling sector of mobile phones and other e-waste is located in countries wherever governments allow it including China, India, Ghana and Nigeria that have relatively low labour costs. These operations generally do not have any pollution prevention measures in place and as a result have a significant environmental impact on their surroundings. The process in these plants typically consists of melting the solder from circuit boards over coal fires and then removal by hand of the various electrical components. As indicated previously, the metal recovered in these types of operations is probably very low, with much of the metal being discharged to the environment through gaseous emissions, liquid discharges or solid residues.

151. Leung *et al.*[137] conducted a survey of workshop and road dust surrounding a recycling facility in China and found elevated concentrations of lead and copper. They concluded that a serious health risk existed for the workers and the general population including children. These findings were replicated in a similar study conducted in India.[138] This health risk is exacerbated by the open burning of plastics and halogenated compounds that contain chlorine and bromide (which represents a potential precursor of dioxins and furans, as mentioned previously). The processing of these materials in modern, properly licensed, permitted or authorised pyrometallurgical or hydrometallurgical plants can avoid these problems: there are such plants in Asia, but they must compete with informal operations and lower standards.

Social dimension

152. The literature review revealed issues of concern mostly in connection with labour-related indicators.[77,139,140,141] The publications show that the lack of appropriate working conditions in electronics recycling plants impose, for example, risks to the health and safety of employees. The publications of James[121] and Williams *et al.*[142] also show that recycling can contribute to national economies. Where recycling facilities operate under ESM conditions, the associated creation of "green" jobs helps meet current policy objectives within most OECD member countries. It has been estimated that recycling provides employment for ten people where disposal only requires one.[143] The social dividend associated with recycling should be explored further.

3.7.3. Key information gaps

153. The economic analysis needs to be updated with more extensive "toll-refining"[144] data, which will provide better cost structure data. For example, for companies that process materials for customers, what is the charge for their smelting and refining services?

154. Different smelters have different capacities and specifications for recyclable feedstock: generally, shredding of mobile phones and printed circuit boards is not an integrated smelter requirement.[145] From a smelter perspective, it is the commodity value of the metals that influences the cost of toll-refining: no premium is paid for shredded feedstock. Concerning mobile phone treatment, it would be worthwhile asking telecommunication companies in OECD countries if they typically require interim processors to destroy/recycle their branded devices rather than having them refurbished and reused in the "grey" market.[11]

155. By definition, the informal sector operates outside formal (regulated) channels and is difficult to quantify. Furthermore, the export of consumer electronic devices for reuse or recycling is difficult to track, whether legal or illegal. In the absence of sound data on informal recycling activities and exports, a comprehensive understanding of the global recycling of mobile phones is likely to remain as an ongoing challenge.

3.7.4. Policy considerations

156. The primary LCA finding regarding recycling of phones and similar devices is that precious and critical metals are lost in processing facilities that do not have effective controls in place. Shredding this material may divert metals into the plastics fraction where the metal is lost to recycling and will contaminate the plastics stream destined for recycling. Alternatively, some parts, especially printed circuit boards and mobile phones, can be fed directly into smelters to recover a very high percentage of available metals. The degree of pre-processing would be a market driven activity in which case policy intervention may not be appropriate. The economic value of all metal scrap drives recovery and recycling operations. Where SMM tools may indicate that the recovery of critical metal would be more beneficial to society as a whole, on account of the environmental and social gains, the recycler's primary motivation will still be economics. A recycler's decision to target one metal over another is based on an assessment of the market as well as an understanding of and a willingness to assume associated risks.

[11] "A grey market involves the buying and selling of goods and services that are not illegal, but the channels used in their distribution are either unauthorized or unofficial." (www.economywatch.com)

3.8. Final disposal

3.8.1. Points of interest

Landfill versus incineration

157. When mobile phones are discarded into the waste fraction, they are essentially lost to the recycling sector. Solid waste is commonly managed through either landfill disposal or incineration. With respect to the former, not all landfills are designed, constructed and operated equally and this will vary from country to country. In the context of this case study a modern engineered landfill with a lining to control leachate should be viewed very differently than an uncontrolled, un-engineered disposal site. These different elements are important where environmental impacts are concerned. Releases and emissions from landfill such as leachate are closely regulated in most OECD jurisdictions.

158. End-of-life mobile phones in developing countries may end up in landfills. The flow of mobile phones to landfill sites in developed countries is expected to be somewhat lower since the scavenging of recyclable discards by the informal sector may be much more efficient than some modern collection systems; however, no estimate of this number has been found in the literature. For Canadian phones, it is estimated that 74% of all mobile phones are *eventually* disposed of (landfill or incineration), and 26% are recycled (see Annex 11 of document “Critical Metals Case Study Annexes” for more discussion on how these numbers were derived, including exports).[12] In the US, the national collection rate is reported to be between <1%,[146] 5%,[107] or 10%:[147] the lower rate may be based on mobile phone sales whereas the higher rate denominator is based on an estimate of disposed phones (*i.e.* those actually available for collection).

159. Incinerators are capital intensive, high tech plants that operate under stringent regulations for emissions to air as well as final treatment of residual ash. There are environmental issues associated with the combustion of electronic devices such as mobile phones but attribution to specific products will be difficult.

Batteries excluded from analysis

160. As stated earlier, the analysis in this case study excludes batteries because they are typically treated at their end-of-life in a separate treatment regime. However, the disposal of mobile phones by users who will not or cannot access a reuse/recycling program, are likely discarding the mobile with its battery attached. This is a limitation of the analysis because in a discarded state the batteries may have a deleterious impact on the surrounding environment.

3.8.2. Implications

Economic dimension

161. Since mobile phones represent a very small proportion of the waste stream, management of them as “waste” will be relatively insignificant. Since the cost of disposal varies both within and between countries, this analysis is highly problematic and not likely to have much bearing on final conclusions except for the fact that, in most cases and unfortunately, disposal of mobile phones (etc.) is often less expensive and more convenient (for the users) than recycling: this represents a significant challenge to industries responsible for product capture under EPR regimes.

[12] This estimate was developed by Natural Resources Canada with information from the Canadian Wireless Telecommunications Association, March 2009. An additional 12% of mobile phones recycled are projected under the assumption that those devices stored or given away (recall Figure 17) are eventually recycled or disposed of.

Environmental dimension

162. Once in a landfill, it is very difficult to trace the impact that the metal content of mobile phones has on leachate due to the tremendous dilution factor that exists and given the fact that mobile phones comprise an extremely small percentage of the total domestic waste stream (with critical metals representing an even smaller fraction of the whole). If they could be accurately measured, certain indicator metals in landfill leachate might reflect possible impact.

163. Information regarding the application of regulatory leachate protocols to mobile phones and their components does exist[148] although Williams[101] argues that TCLP[13] tests are much more aggressive than conditions within typical municipal waste landfills. Nevertheless, these studies indicate that many, but not all mobile phones qualify as hazardous waste according to U.S. leachate protocols. The primary metals of concern in these studies were lead, copper, nickel, antimony and zinc. When mobile phones were mixed with other municipal waste in column tests, leachate metal concentrations were lower than regulatory limits and would be expected to remain low as long as the pH of the landfill was not acidic.[149] The Solid Waste Association of North America (SWANA) has compiled some work in this area. This review led them to conclude that "even in older unlined landfills the risk of discharge of heavy metals leached from e-waste to the environment appears to be very small."[101] A more comprehensive review should be performed to determine if there is any information linking mobile phones or e-waste to elevated concentrations of critical metals in landfill leachate.

164. Incineration is another possible "end-of-life" scenario for mobile phones if they are disposed of with municipal waste. A number of studies have examined the behaviour of e-waste under conditions typical in these plants.[150,151] Results have shown that a number of metals were volatilized, including As, Cd and Sb; other metals such as Ni and Ga remained in the process residual. Another concern identified with computer circuit boards was the formation of emissions with estrogenic activity. As well, studies have shown that plastics and other hydrocarbons may form halogenated hydrocarbons such as dioxins and furans.

Social dimension

165. A few publications made references to the impacts of e-wastes disposal to the health and safety of local communities surrounding landfills that receive that material.[44,83,139] It is expected that the social consequences of buried or burned mobile phones correlates strongly with environmental impacts.

3.8.3. Key information gaps

166. As already mentioned there is no firm data on how many mobile phones (and the critical metals contained therein) are disposed of with domestic waste and that end up at either a landfill or an incinerator. The issue of whether a discarded mobile phone – particularly with respect to critical metals contained therein – is a serious environmental concern or not deserves further attention. In reality, when these devices are disposed of, they are not shredded or grinded beforehand. Therefore, in a more or less undamaged state, how will an obsolete mobile phone decay in a landfill environment and over what time? Similarly, what happens to the critical metals when the mobile phones are incinerated? What are the true impacts?

167. For those that are sent to landfill there is very little work that has been done on its environmental impact on the surrounding ground and surface water. With respect to incineration, data are required from

[13] "The TCLP, or Toxicity Characteristic Leaching (not Leachate) Procedure is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphasic wastes." http://www.ehso.com/cssepa/TCLP.htm

operating plants; data of interest would be information related to compliance with regulations and the concentration of contaminants in gaseous emissions, liquid discharges and solid wastes. With this type of information the relative environmental merits of one disposal scenario over another could be assessed. However, given the relatively small proportion of mobile phones in the waste stream, it is unlikely that their contribution towards overall emissions will be significant let alone detectable.

3.8.4. Policy considerations

168. One approach to keeping recyclable materials and products out of the disposal stream is for the appropriate jurisdiction to introduce targeted disposal bans. Bans are usually brought in to play after an EPR program has been launched or when a comprehensive recycling program has been established. Bans are difficult to enforce but they carry a strong message that may nonetheless result in increased capture rates.

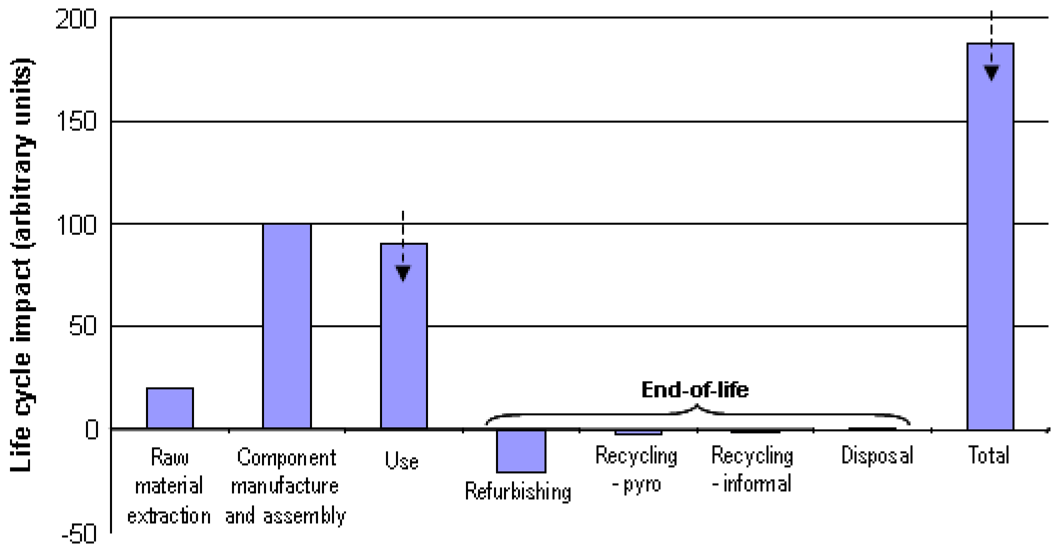
169. Once materials or products reach "final disposal" further recovery is usually not possible (if incinerated) or not often done (landfill). Where mobile phones are concerned, their dispersion in a landfill environment is probably enough to deter re-concentration of the contained metals. Nevertheless, landfill mining[152] has been tried in a number of locations though it remains uncertain whether the recovery of critical metals is economically feasible or of interest. Public-private partnership funding of research in this area may be a policy direction worth taking in the context of SMM. Pre-planning activities should consider the environmental and social implications of opening a sealed site since these costs may be very large: this raises the dilemma of choice and trade-offs since a 50 acre landfill might contain tens of millions of dollars of scrap metal.[153]

3.9. Life cycle stages overview and comparison

170. Critical metals such as Be, Pd, Pt and Sb are essential for the functionality of mobile phones including a reduction in the impact of the use phase (involving energy consumption). As discussed previously, the stages in the life cycle of mobile phones can be described as follows: (1) raw material extraction, (2) component manufacture and assembly, (3) use, and (4) end-of-life (EOL) comprised of (a) refurbishing/reuse, (b) recycling – pyro, (c) recycling – informal, and (d) disposal.

171. Based on the review of literature, discussions with industry experts and preliminary analyses, a model to estimate the "impact" or burden of each stage can be created to help inform policy decisions regarding the post-consumer use of electronic devices such as mobile phones. Figure 19 juxtaposes the estimated "impact" of the various stages using *arbitrary* units for the life cycle of a thousand mobile phones. By using an overall impact metric as a yardstick, it ensures that a common reference is used over the whole life cycle for the aspects that have environmental relevance. The raw material extraction stage, for example, is dominated by the impact (GHG or energy) of primary production of metals. Since mobile phones (that contain printed circuit boards like other consumer electronic devices) are extremely complex, a significant share of the total impact is associated with the manufacturing stage.

Figure 19: Conceptual impacts for various life cycle stages of a mobile phone



172. The first use of a mobile phone is likely to extend from 18 to 24 months. For the EOL, four scenarios are possible. In order to make a quantitative description, the flow of mobile phones to each of the EOL scenarios will be required.

a) The impact of the use phase depends on the source of energy, the type of battery and the stand-by power requirement. Due to technological improvements, the relative impact of the use phase has been (and will continue to be) reduced over time.

b) The impact of EOL – refurbishing has a negative impact (or benefit) because it extends the life of a mobile phone. It requires less energy to refurbish a mobile phone that to manufacture a new one. The functionality of critical metals in the product is extended.

c) The impact of EOL – recycling – pyrometallurgical processing also has a negative impact. Environmental impacts due to the transport of EOL mobile phones and the impact of the smelting process needs to be accounted for. But because the process produces metals of high purity it offset primary metal production. The size of the credit will depend on the flow of EOL mobile phones directed to smelters and of the metallurgical efficiency of the smelter that extracts the metals including critical ones.

d) The impact of EOL – recycling – informal. The environmental impacts due to the transport of EOL mobile phones and the impact of the informal recycling sector needs to be better accounted for in the overall analysis. Since the process produces gold, it offsets primary metal production. The size of the credit depends on the flow of EOL mobile phones that are handled by the informal recycling sector and by the efficiency of their gold extraction activities (which is relatively low).

e) The impact of EOL – disposal. No credit is given during this stage because no material recovery occurs. All the metals will be lost and environmental impact of associated transportation will be incurred.

173. Figure 19 is a representation of the potential impacts of a mobile phone over its entire life cycle. A complete LCA for a specific mobile phone model would require that assumptions be made regarding its place of use and its end-of-life fate. That is an impossible task. Thus, Figure 19 should be used as a qualitative guide only. For example, where the impact of component manufacture and assembly is greater than raw material extraction, an opportunity exists to reduce the former by extending the life of the mobile phone.

4. AN INVENTORY OF KNOWLEDGE GAPS

174. While every effort has been made to review and synthesize the literature on mobile phones, critical metals and associated recycling activities, it is possible that the gaps summarized in this section have been addressed elsewhere. This inventory of real or potential knowledge gaps is intended to stimulate further research and discussion as a basis for developing a more robust understanding of the strengths and limitations of SMM thinking. This first part of this summary is organized along the life cycle while the second offers general gaps commentary.

Stage 1: Raw material extraction and processing

- LCA data are sparse for the production of critical metals and many other materials. In fact, GHG and cumulative energy demand data for antimony, beryllium or tantalum are not available from *ecoinvent.*
- Need to allocate emissions among the co-products based on their physical interrelationships.

Stage 2: Design

- Is there an industry trend towards “design for recycling” and what are the primary drivers for these initiatives?
- What can governments do to influence or support design for recycling?

Stage 3: Manufacturing

- What are the (non-aggregated) GHG emissions and cumulative energy requirements at the extraction/refining stage and at the manufacturing stage?
- Are there hidden social costs associated with the manufacture of mobile phones and can SMM policy mitigate them?

Stage 4: Product use

- Is better data available regarding the global flow of new, used and obsolete mobile phones? Can better data be assembled? A summary of mobile phone flows across the OECD area would provide a good start.
- Is there any way to measure and compare the economic and social benefits of mobile phone use in these and other countries with the environmental impacts of informal recycling or inadequate final disposal practices when these devices are finally discarded?

Stage 5: End-of-life

- Better cost data are required to better understand the mobile phone sorting stage, whether manual or semi-automated.

- Need for better data regarding the triage and resulting flow of collected mobile phones within/between OECD and non-OECD countries (that is, what is the extent and nature of interim processing of mobile phones?).
- Need for data sets from other countries and more investigation to determine why consumers hoard mobile phones, for how long and what eventually happens to them.

Stage 6: Refurbish and reuse

- What are the environmental impacts associated with the activity of refurbishing?
- How feasible is refurbishment and what is the life expectancy of a refurbished phone?
- How strong are the links between refurbishment and reuse, and the economic benefits associated with increased access to cost-effective telecommunications technology in developing countries?
- What are the costs to refurbish a mobile phone and what are they comprised of (labour, equipment, energy, etc.)?
- If phone reuse ended, would the production of new units need to be ramped up and, if so, by how much? (re: product displacement rates)

Stage 7: Recycling

- When companies process e-waste for customers, what is the charge for their smelting and refining services?
- Are there any measurable losses of precious or critical metals when mobile phones are treated advanced interim processing facilities?
- The extent of the informal recycling sector around the globe is unknown but probably represents a persistent data gap.
- What are the energy efficiencies and metallurgical yields experienced in hydrometallurgical plants?
- A more detailed economic analysis is required to assess the cost/benefits of each recycling scenario: informal recycling versus the smelters since the data presented in Table 3 are not highly representative.

Stage 8: Final disposal

- There do not appear to be any effective national or regional systems for tracking the number of mobile phones that end up in landfills or incinerators. Therefore, total discard numbers are unknown (though a spreadsheet model to estimate these volumes, based on Canadian data, is appended to this report for the consideration of SMM Steering Committee members).
- What happens to the critical metals in mobile phones when they are landfilled or incinerated?

General gap comments

- Material supply and market demand have a strong influence on prices. Relative material prices drive material substitution that, in turn, has a direct impact on a metal's criticality. Where metals are concerned, an inventory and analysis of material substitution may help reveal the tenuous nature of the "critical" label. For example, beryllium oxide and antimony trioxide are already being replaced by less toxic substances by some manufacturers.[154] This may reduce their criticality.

- The emissions related to the production of antimony and beryllium are not known, but that information will not change the environmental weight profile: since the relative price of these metals is low, it can be inferred that the amount of energy required to produce them is also low and this would suggest a marginal environmental impact in terms of GHGs. In the absence of data, assumptions can be used to bridge gaps but this will reduce the reliability of any findings.
- If reduced criticality is an SMM goal, the recovery of metal from post-consumer mobile phones may help. To develop a better understanding of how this might be achieved, it would be beneficial to know the total flow of mobile phones to integrated smelters plus their metallurgical yield per metal (these data could be aggregated to protect confidentiality). An overview of where OECD generated mobile phones end up would be helpful since it is likely that the majority of smelter feedstock (in the form of electronics) is sourced from developed countries rather than developing ones.
- The economic variables used in eco-efficiency models (see Figure 12) are region dependant; while they may have been measured in Europe, these data are less known in other OECD countries.
- Tonne-kilometre data and transport mode are largely unknown where mobile phones are concerned though proxy numbers may be useful for estimating potential environmental impacts with the help of life cycle databases such as *ecoinvent*. However, it is anticipated that the contribution of transportation towards the overall life cycle emissions picture for critical metals is relatively small.[155]
- This report offers a somewhat static view of the world although it is noted that mobile phones have shrunk in size yet increased in functionality since they were introduced into the market place in the 1980's. The impact of innovation and new technology will likely result in different mobile phones with different material content that will have economic, environmental and social implications in the future (see Annex 14 of document "Critical Metals Case Study Annexes" for one new concept from Nokia).

5. POLICY BARRIERS AND OPPORTUNITIES

175. In the terms of reference for this case study, the SMM Steering Committee listed specific issues to be addressed. Therefore, in the context of critical metals and mobile devices, the following responses are provided in order to stimulate further thought and discussion.

5.1 Macro and micro environmental impacts over the full life cycle

176. In the approach taken for this case study, the environmental dimension is examined at each stage of the life cycle of critical metals, beginning with raw material extraction and processing and ending with final disposal. Since recycling of the metal content within these devices has significant potential to maximize resource efficiencies, it is important to recognize that while macro environmental benefits may be accrued at a regional, national or global level, there may also be negative micro environmental impacts associated with ineffective, informal recycling activities. Specifically, since recycling saves energy and reduces greenhouse gas emissions, there is a global or macro benefit. However, if the health and safety of workers or local populations are compromised as a result of harmful emissions associated with informal recycling operations, then the micro environmental effect is negative. The challenge for policy makers therefore is to weigh these benefits and impacts and identify the best path forward.

5.2 System integration – supply chain

177. In the world of metals, there are traditionally two sources of materials: primary and secondary (also referred to as recyclable). The primary supply chain generally involves exploration, mine development, extraction of raw materials, smelting of ore into concentrates, refining and casting, rolling or extruding. The recycling supply chain begins with scrap metal collection and is followed by a mix of processing activities that may involve shredding, screening, magnetic, eddy-current or heavy media separation, and further volume reduction measures. State-of-the-art smelters and steel mills process primary and/or recyclable feedstock. At the end of the chain (*i.e.* in the metal product), the difference between primary and recycled feedstock cannot be determined.

178. Information and communication technology manufacturers, in turn, need to recognise the challenges and opportunities that are arising via "vertical disintegration, international procurements, new information technologies and increasing pressure from customers on responsiveness and reliability, and the globalization of operations and markets."[156] One strategic response to these recent trends may be Environmental Supply Chain Management (ESCM) that is defined as "the set of supply chain management policies held, actions taken, and relationships formed in response to concerns related to the natural environment with regard to the design, acquisition, production, distribution, use, reuse, and disposal of the firm's goods and services."[157] LCA is the tool that organizes and informs ESCM.

179. The key issues for supply chain management may occur at three levels: strategic, tactical or operational. Some of the issues include configuration of the distribution network, inventory control, distribution strategy, integration and strategic partnerships, product design, IT and decision support systems, and customer value.[158] Where reverse logistics is concerned, policy makers need to consider the configuration and inventory control issues in particular since EPR introduces a new element in the production-consumption cycle where points of sale may become points of return and many retail outlets were not designed with that function in mind.

5.3 Effects on "natural capital"

180. Where metals are concerned, "natural capital" may refer to mineral reserves. However, since infrastructure contains metal, and since recycling is a well-established industry, it could be argued that the metal used to make buildings, automobiles, ships, pipelines and sundry consumer products could be considered as "capital" as well that eventually will be recycled when it reaches end-of-life. Unlike paper and plastics, metals can be theoretically recycled infinitely at the atomic level.[159] The economy is simply shifting natural assets (*i.e.* minerals and metals) from one location (underground) to another (infrastructure). The challenge for policy-makers, regulators, industry stewards, program operators and consumers is to ensure that this natural capital is not lost; that we move away from the traditional linear economy mindset in which natural capital is used and discarded; and that current and future production/consumption activities be undertaken in a manner that is environmentally, economically and socially sustainable.

5.4 Costs and benefits of SMM

181. Inevitably, there are costs and benefits associated with pursuing SMM but it is often very difficult to assess and/or assign values. For example, one of the SMM tools used in this case study is LCA. The cost of an LCA depends on the goal and scope of the study; in particular, the gathering and analysis of data can be time-consuming and expensive. The case study on critical metals found in mobile phones has relied on readily available primary data – no primary research was conducted, essentially to minimize costs. Decision-makers are rightly challenged with the task of assessing the effectiveness (especially benefits) of policies such as SMM. However, since there are always extenuating circumstances or external variables that influence outcomes, it may be impossible to isolate cause and effect. Nevertheless, the use of LCA and SFA does expand our understanding about the need for enhanced material efficiency planning.

182. Traditional economic analysis recognizes the fact that certain trade-offs are required. Where SMM is concerned, should equal consideration be given towards environmental, economic or social aspects or is one of these "pillars" thicker than the others? In this regard, the challenge for policy makers is in seeking balance where consensus from stakeholders may be difficult to achieve.

5.5 Consumer and producer interests

183. Consumer and producer interests are "negotiated" in the global marketplace. The individual consumer is powerless but as a whole, the aggregated purchasing power of consumers with a preference for smaller, cheaper, greener and cleverer devices, for example, directly influences new product designs. A producer, on the other hand, is either creating new demand or is responding to it. In reality, there is considerable tug and pull between these two players but there is a third player, and that is government in its role as a policy-maker and a regulator. Also, the promotion of SMM concepts by government may help the marketplace to recognize the difference and the importance of external and internal costing practices. In particular, product pricing should include end-of-life management: in this way the consumer can make more informed decisions about purchases and producers can respond accordingly.

5.6 International and cross-sectoral dimensions

184. Both critical metals and mobile phones have international and cross-sectoral dimensions. Both primary and recyclable metals are globally traded commodities. Consumer electronic devices such as mobile phones are manufactured, distributed, used and discarded around the world. These devices are comprised of plastics, glass as well as ferrous and nonferrous metals. Multi-stakeholder efforts to address the flow of post-consumer electronic products have been undertaken at regional, national and international

levels. However, given the fact that SMM-based policy-making is still evolving, the complexity of a world economy in which materials, products, people and money are in constant circulation requires approaches in which policy-makers think globally but act locally. Recent global thinking undertaken by MPPI (Mobile Phone Partnership Initiative), PACE (Partnership for Action on Computing Equipment) and StEP (Solving the E-waste Problem) supports local action within a global context.

5.7 Effects on the competitiveness of firms in related industries

185. Any regulatory intervention concerning the use of certain materials or involving the production and trade of certain goods, is likely to benefit one business over another: the analysis of critical metals found in mobile devices touches on this issue briefly. If it were determined that the "best" solution for end-of-life management of mobile phones were to send them to integrated smelters, this would impact: (1) the interim processors that shred mobile phones and motherboards in developed countries and (2) the informal recycling sector in developing countries. Where interim processors are concerned, the volume of mobile phones may be insignificant compared to other electronics feedstock but, as indicated previously, mobile phones are relatively rich in precious metals (measured in thousands of dollars per ounce). Also previously noted, the need to ensure data security and/or reduce shipping costs suggests a continuing role for interim processors who will also always seek to maximize their economic returns by optimising efficient material recovery. Where informal recyclers are concerned, fewer materials would be received and the relative economic impact may be more profound even impacting operations that may be sustainable; however, an accurate or reliable assessment of this impact will be difficult to conduct given the complexity of material flows as shown in Annex 4 of document "Critical Metals Case Study Annexes".

186. The concept of the "level playing field" is frequently discussed but is it really possible? Competitive advantage arises where standards or rules are different in one jurisdiction compared to another. A business with the best technology in the world for managing a recyclable device may not be able to compete with another that has a rudimentary or even sub-standard approach. A national "flow control" policy to support the former over the latter may have World Trade Organization implications but might help support a domestic political agenda.

5.8 Social implications of SMM

187. Social implications could involve a wide range of matters that affect society. They can involve negative problems, such as violence, conflict, injustice, corruption, racism, war, and unemployment; or there are positive effects, such as job creation, peace, comfort, convenience, and pleasure. These issues can impact society at different levels, from small employee groups, to local communities or the global population in general. In addition, the effects can overlap, combine and/or change across the life cycle of materials. To date, it does not appear that a single SMM initiative or methodology addresses the diversity of social issues in the life cycle of materials. As several 2008 OECD studies have shown, efforts usually concentrate on particular aspects and certain life cycle stages. Recent developments in the emerging field of social life cycle assessment are, nonetheless, hinting at comprehensive ways that may help to frame this challenge. The preliminary development of an approach to include the social dimension in an LCA context is attached in Annex 12 of document "Critical Metals Case Study Annexes".

5.9 Developing world implications

188. It has been proposed by some that post-consumer electronic devices be sent to integrated smelters that can recycle the materials in the most cost-efficient and environmentally sound manner, removing access to these materials for the informal recycling operations that tend to be located in developing countries. However, consideration needs to be given towards the needs of developing countries for the sustainability of existing ESM facilities and the development of new ones to treat used electronic and

electrical equipment in such a way as to address the social dislocation that is associated with the transformation of informal economies.

189. Note: It is reported that much of the existing flow of expired electronic devices ostensibly designated for reuse is illegal and, as a result of smuggling or sham reuse programs, ultimately is directed to informal recycling operations. End-of-life products that still have material value and can generate real economic activity in developing countries raise a dilemma for regulators in developed countries. Despite regulatory and enforcement infrastructure that is established to reduce environmental and social impacts, the economic imperative will probably continue to provide ample incentive for illegal trade.

5.10 Mining activities

190. Mining is a critical part of the life cycle for all metals and though recycling plays a vital and permanent role within the metals economy, largely because of ongoing growth around the world, the need for mines and new ores will not disappear. However, a significant amount of work is being conducted in other forums to address the environmental and social implications of mining companies wherever they operate. For example, the International Council on Mining and Metals (ICMM) has created a Sustainable Development Framework that identifies the need for materials stewardship, including a list of ten principles in which number 8 states that the council membership will "facilitate and encourage responsible product design, use, re-use, recycling and disposal".[160] The Mining Association of Canada promotes sustainable mining principles in which the industry "must demonstrate a responsible approach to social, economic and environmental performance."[161] The Minerals Council of Australia and the National Mining Council (U.S.) makes similar statements about responsible or balanced development.[162,163]

5.11 Design for environment

191. Where the recycling of relatively complex consumer products is concerned, design for environment (DfE) is of utmost importance. Specifically, when a device is first conceptualized, it is becoming increasingly recognized that the designer should take recycling into consideration. This can be achieved in a number of ways and in this regard much work has already been undertaken. Insofar as policy-making is concerned, the impetus for encouraging design for environment may lie with the introduction of user pay principles and extended producer responsibility. However, public interest in individual green procurement is influencing mobile device manufacturers who are already responding with products that have been designed with environmental considerations in mind.[164] It will be interesting to see if future sales of these more eco-friendly mobile phones justify their continued production. Recall Section 3.2 for further discussion of the DfE concept in which some phone manufacturers are phasing out antimony, beryllium, chlorine and bromide.

5.12 Material substitution

192. Material substitution is one of many control options that may be considered in optimizing the sustainable use of critical metals. When metals are in short supply, at risk or indeed expensive, design engineers consider alternative materials. This (particularly high prices) will lead to reduced demand for the metal in question, thus easing scarcity. The platinum group metals (PGM) can be substituted for each other though in some cases (*i.e.* auto catalysts) platinum (Pt) cannot be completely removed because of its unique properties. However, since palladium (Pd) is less costly, much effort is made to substitute Pd for Pt wherever possible. Material substitution must be carried out on a case-by-case basis, using risk assessment and exposure data with sufficient due diligence to avoid unintended consequences, including adverse social and economic impacts. In some cases plastics are taking the place of metal parts: the benefit of this may be lower costs and lighter weight while the disadvantage may be poorer product durability or reduced recyclability of a lower value material.

5.13 Impact of international agreements and REACH on trade and recovery of materials

193. International agreements such as the Rotterdam Convention and regional regulations such as REACH have the potential to affect the trade and recovery of recyclable materials and products. During the literature review on critical metals and mobile phones, specific references to barriers to their trade were not encountered other than issues associated with illegal traffic and the existence or absence of appropriate facilities for ESM in developing countries. Further research is needed to determine what barriers may exist to future policies to maximize the recovery and recycling of critical metals in these and other products.

6. CONCLUDING OBSERVATIONS

194. A closer examination of the working definition of SMM suggests that its overriding objective is *the promotion of sustainable materials use on a global basis*: this is a reasonable role for national governments to play and might lead, for example, to domestic programs that support the implementation of product stewardship initiatives in which the recovery of contained materials is optimized. There are six *guiding elements* with which to consider the relevance, usability and effectiveness of SMM:

195. First, the **integration of related actions, policies and programs** is an important guiding element of SMM since duplication of initiatives is usually an inefficient use of expertise, time and funds. Every effort should therefore be made to identify and understand international, national and/or regional activities already underway or planned. *Integration* is the key term in the working definition of the SMM approach.

196. Second, the **reduction of environmental impacts** over the life cycle of a material is already a policy objective of OECD member states (typically accounted for under SD) but in practical terms, and in light of this case study on critical metals, some knowledge gaps persist, as identified in Section 4. Collaborative action to assemble missing data on sustainable materials use will enhance overall SMM (and SD) efforts.

197. Third, the **preservation of natural capital** can be indirectly ensured through better sustainable material use practices. Natural capital per se is more about natural resources than materials or products though the policy linkage between all three is obvious. This flags the need to ensure clarity about the boundaries of SMM relative to natural resource management, for example.

198. Fourth, a central tenant of SMM is the **life cycle approach** (LCA). The consideration of the economic, environmental and social implications of a material throughout its life cycle will enable decision-makers to develop policies and programs that are balanced and equitable. LCA is a powerful analytical tool but its usefulness is contingent on the acquisition of comprehensive and sound data. Progressive businesses are already using LCA to introduce material management efficiencies in order to strengthen their bottom line.

199. Fifth, **economic efficiency** and related business innovations are driven by competition in a fair, open and transparent marketplace. Government intervention in the economy, through the introduction of non-trade tariff barriers for example, creates market distortions with uncertain consequences. Therefore, effective SMM policy-making requires partnership and engagement with the private sector in order to maximise benefits and minimise systemic costs.

200. Sixth, consistent with SD, it is important to **address social equity** issues by engaging stakeholders and elevating their awareness of the social impacts associated with the use of materials across the life cycle spectrum. The social aspects of material use are difficult to measure and sometimes impossible to reconcile when a product component supports an invaluable social function (such as increased communication) though its eventual disposal may cause negative environmental and/or social (*i.e.* health) concern.

REFERENCES

[1]. A study on methodologies relevant to the OECD approach on sustainable materials management *www.olis.oecd.org/olis/2007doc.nsf/LinkTo/NT00008902/$FILE/JT03250103.PDF* (accessed May-2009)

[2] The Congress of the United States Congressional Budget Office: Strategic and Critical Nonfuel Minerals: Problems and Policy Alternatives: Washington DC, 1983

[3] The U.S. government - Report of Meeting, Department of Defense, Strategic Materials Protection Board, Held on December 12, 2008 *www.acq.osd.mil/ip/docs/report_from_2nd_mtg_of_smpb_12-2008.pdf*.

[4] Morley, N and Eatherley, D Material Security Ensuring Resource Availability for the UK Economy. C-Tech Innovation Ltd; Resource Efficiency, London 2008.

[5] Behrendt, S, Scharp M, Erdmann L, Kahlenborn W, Feil M, Dereje C, Bleischwitz R, Delzeit R. Rare metals, Measures and concepts for the solution of the problem of conflict-aggravating raw material extraction – the example of coltan. Umweltbundesamt (German Federal Environmental Agency), 2007.

[6] Euromines. Security of international supply *www.europeanmineralsfoundation.org/Hebestreit_Communication_Nov_2008_final.ppt* (accessed May-2008).

[7] Classen M, Althaus HJ, Blaser S, Scharnhorst W, Tuchschmid M., Jungbluth N. Life Cycle Inventories of Metals. Final report, ecoinvent v2.0 No. 10, Swiss Centre for Life Cycle Inventories, Duebendorf, CH 2007

[8] National Research Council of the National Academies. Minerals, Critical Minerals, and the U.S. Economy. The National Academies Press. Washington DC, 2007.

[9] *www.unep.fr/en/*

[10] Buchert, M.; Schüler, D.; Bleher, D.: Critical metals for future sustainable technologies and their recycling potential. Öko-Institut and UNEP-DTIE. Darmstadt, 2008.

[11] National Research Council of the National Academies. Minerals, Critical Minerals, and the U.S. Economy. The National Academies Press. Washington DC, 2007, p. 9.

[12] See Tantalum-Niobium International Study Center, *www.tanb.org/* for more details

[13] U.S. Geological Survey, *http://minerals.er.usgs.gov/minerals/pubs/mcs/*

[14] Composite of data from World Mining Data (2008) and the U.S. Geological Survey (2008), assembled by and presented in (EU) Commission Staff Working Document to accompany “The raw Materials Initiative,” {COM(2008) 699} The original idea for this graphic is from C. Hocquard, BRGM, *www.brgm.fr*

[15] MPPI: Guidance document on the environmentally sound management of used and end-of-life mobile phones, Basel Convention/UNEP, 2006.

[16] Johnson J, Harper EM, Lifset R, Graedel TE. Dining at the periodic table: metals concentrations as they relate to recycling. Environmental Science and Technology, 2007; 41: 1759-1765. (The original material is from T. McManus, Intel Corporation, 2006).

[17] Hagelüken, C. Study to test the recycling guideline. Mobile Phone Partnership Initiative (MPPI) 2008-02

[18] TU World Telecommunications/ICT indicators (WTI) database, *www.itu.int* (accessed May 2009)

[19] *www.purchasing.com/article/CA6635102.html* (accessed May 2009)

[20] *www.handcellphone.com/archives/nokia-vertu-ultimate-cellular-phones-like-ferrari-in-car-industry* (accessed June 2009)

[21] RIS International Ltd., MacViro Consultants Inc. & Jack Mintz & Associates. Waste Electronic and Electrical Equipment Study. 2005, Waste Diversion Ontario

[22] Five Winds International. A Study on Methodologies Relevant to the OECD Approach on Sustainable Materials Management. OECD, 2008

[23] Five Winds International. A Study on Methodologies Relevant to the OCED Approach on Sustainable Materials Management, ENV/EPOC/WGWPR(2007)5/FINA, 2008

[24] Lehni, Markus. Eco-efficiency: Creating more value with less impact, World Business Council for Sustainable Development. Switzerland, 2000

[25] Hagelüken, C. Materials Flow of Platinum Group Metals - System Analysis and Measures for a Sustainable Optimisation. IPMI 27th International Precious Metals Conference. 2003.

[26] *www.yale.edu/cie/* (accessed March 2009).

[27] A Report by the Global Metal Flows Group, Anthropogenic Metal Stocks: Scientific Synthesis, UNEP International Panel on Sustainable Resource Management, (Initial Draft as of October 23, 2008).

[28] International Organization for Standardization (ISO), ISO 14044: 2006, Environmental management – Life cycle assessment – Requirements and guidelines

[29] International Organization for Standardization (ISO), ISO 14040: 2006, Environmental management – Life cycle assessment – Principles and framework

[30] Huisman, J, Stevels, ALN, Stobbe, I. Eco-efficiency considerations on the end-of-life of consumer electronic products. IEEE Transactions on Electronic Packaging Manufacturing 2004; 27[1], 9-25.

[31] Huisman, J, The QWERTY/EE Concept - Quantifying Recyclability and Eco-Efficiency for End-of-Life Treatment of Consumer Electronic Products. 2003. Delft University of Technology.

[32] Dubreuil, A, Young, SB, Atherton, J, and Gloria, T. Metals Recycling Maps and Allocation Procedures in Life Cycle Assessment. International Journal of LCA, Submitted 2009.

[33] Jørgensen, A, Le Bocq, A, Nazarkina, L, Hauschild, M. Methodologies for social life cycle assessment. International Journal of LCA 13[2], 96-103. 2008.

[34] Fonseca, A, Young, SB. (University of Waterloo, Canada) Incorporating Social Aspects into Sustainable Metals Management: Literature Review and Framework for Advancing Research, unpublished paper prepared for CANMET, Natural Resources Canada **,** 2009.

[35] Beloff, B, Tanzil, D, Lines, M. Sustainable development performance assessment. Environmental Progress, 2004; 23 [4]: 271-276.

[36] Verhoef, E. V., Reuter, M. A., and Scholte, A. A dynamic LCA model for assessing the impact of lead free solder. Kongoli F., Itagaki K., Yamauchi C., Sohn H.Y., Kongoli F., Itagaki K., Yamauchi C., and Sohn H.Y. 2, 605-623.

2003. San Diego, CA, TMS. Yazawa International Symposium: Metallurgical and Materials Processing: Principles and Technologies; High-Temperature Metal Production. 2 March 2003 through 6 March 2003.

[37] Deubzer, O. Explorative study into the sustainable use and substitution of soldering metals in electronics: ecological and economical consequences of the ban of lead in electronics and lessons to be learned for the future. January 30, 2007. Delft University of Technology.

[38] Graedel, TE. Material substitution: a resource supply perspective. Resources, Conservations and Recycling 2002; 34: 107-115.

[39] Hocquard, C and Deschamps, Y. Technologies innovantes et métaux High-Tech. 2008. BRGM

[40] *www.platinum.matthey.com/* (accessed June 2009)

[41] *http://minerals.usgs.gov/minerals/pubs/commodity/platinum/550498.pdf* (accessed June 2009)

[42] Seymour R, O'Farrelly JI. Platinum-Group Metals. John Wiley & Sons, Inc., 2001.

[43] CorpWatch. Barrick's dirty secrets: communities worldwide respond to gold mining's impacts. 2007. Oakland, CorpWatch. Alternative Annual Report.

[44] Cox S. Cell Phones Generate Particularly Dangerous e-waste. In: Bily CA, editor. What are the impacts of e-waste Greenhaven Press, Farmington Hill, 2009

[45] Farrell, L, Sampat, P, Sarin, R, Slack, K. Dirty Metals: Mining, Communities and the Environment, Washington and Boston: Earthworks and Oxfam America. 2004

[46] Friends of The Earth. Mining, hands off! Why international financial institutions must stop drilling, piping and mining. Amsterdan. 2003

[47] Grossman E. Prison Recycling Programs Are Dangerous for Inmates. In: Bily CA, editor. What are the impacts of e-waste? Greenhaven Press, Farmington Hills, 2009

[48] Global Witness. Paying for protection: the Freeport mine and the Indonesian security forces. 2005. Washington, Global Witness.

[49] Global Witness. Heavy Mittal? A state within a state: The inequitable mineral development agreement between the government of Liberia and Mittal Steel Holdings NV. 2006. Washington, DC, Global Witness Publishing Inc.

[50] Hayes, K, Burge, R. Coltan mining in the Democratic Republic of Congo: How tantalum-using industries can commit to the reconstruction of the DRC. Fauna & Flora International 2003.

[51] Norbrand, S, Bolme, P. Powering the mobile world: Cobalt production for batteries in the DR Congo and Zambia. 2007. SwedWatch.

[52] Poyhonen, P, Simola, E. Connecting components, dividing communities: Tin production for consumer electronics in the DR Congo and Indonesia. 2007. FinnWatch.

[53] Steinweg, T, de Haan, E. Capacitating electronics: the corrosive effects of platinum and palladium mining on labour rights and communities. 2007. Amsterdam, SOMO - Centre for Research on Multinational Corporations.

[54] *www.nrcan-rncan.gc.ca/mms-smm/nmw-smc/csr-csr-eng.htm* (accessed August 2009)

[55] Shapiro, K, White, AL. *Right from the start: Product stewardship through life-cycle design*. Corporate Environmental Strategy 1999; 6: 14.

[56] For example, The CIM Institute at Cranfield University (UK), *www.lar.ee.upatras.gr/icims/acadnodes/cranf.htm#areas* and the Center for Sustainable Systems at Michigan University (US), *http://css.snre.umich.edu/*

[57] Messner, F. Material substitytion [sic] and path dependence: empirical evidence on the substitution of copper for aluminum. 2002. UFZ – Centre for Environmental Research, Leipzig, Germany

[58] Hagelüken, C, Buchert, M. The mine above ground - opportunities & challenges to recover scarce and valuable metals from EOL electronic devices. International Electronic Research Corporation (IERC) Salzburg. 2008.

[59] Atherton J. Declaration by the metals industry on recycling principles. International Journal of Life Cycle Assessment 2007; 12: 59-60.

[60] International Beryllium Research Conference, *www.cihr-irsc.gc.ca/e/28332.html* (accessed September 2009)

[61] Rifer, W, Brody-Heine, P, Peters, A, Linnell, J. Closing the loop: Electronics design to enhance, reuse/recycling value - final report. Green Electronics Council, National Center for Electronics Recycling, e-Strap News. 2009

[62] Nokia, 2006, the Integrated Product Policy Pilot on Mobile Phones (Project Manager: P. Singhal)

[63] See The Minerals and Metals Policy of Canada at *www.nrcan-rncan.gc.ca/mms-smm/poli-poli/pdf/mmp-eng.pdf*, p. 11

[64] Schwartz, J. & Gattuso, D.J. 2002. Extended Producer Responsibility: Reexamining Its Role in Environmental Progress, Reason Public Policy Institute, Study 293 (*www.reason.org/news/show/127536.html*)

[65] Tojo, N., Effectiveness of EPR Programme in Design Change, The International Institute for Industrial Environmental Economics, Lund University, Sweden: 2000 (*www.iiiee.lu.se/Publication.nsf/$webAll/4D6FD78D3D6460FEC1256C56002B98E7/$FILE/Tojo_EPRfordesignchange2001final.pdf*)

[66] *http://iprworks.org/* (accessed Feb-2010)

[67] Five Winds International, March 2009. Design for Environment (DfE) Best Practices Lessons for British Columbia Ministry of Environment. (*www.env.gov.bc.ca/epd/recycling/resources/reports/pdf/DfE.pdf*)

[68] *http://walmartstores.com/Sustainability/9264.aspx?p=9191&sourceid=milestone&ref=* (accessed July 2009)

[69] *http://ecoble.com/2009/01/06/green-cell-phone/* (accessed July 2009)

[70] IDATE, The World Telecom Services Market (19th Edition), *www.idate.fr/pages/index.php?rubrique=etude&idr=16&idl=7&idp=326* (Accessed may 2009)

[71] Astill, K, Griffith, M. Clean up your computer: Working conditions in the electronics sector. 2003,London: Catholic Fund for Overseas Development (CAFOD).

[72] CEREAL. New Technology Workers: Report on Working Conditions in the Mexican Electronics Industry. 2006. Centro de Reflexión y Acción Laboral (CEREAL)

[73] Chan, J. High-tech - no rights? A one year follow up report on working conditions in China's electronic hardware sector. 2008. Mongkok and Lusanne, Pain pour le prochain action de carême and SACOM.

[74] Chan, J, Haan, E, de Nordbrand, S, Torstensson, A. Silenced to deliver: mobile phone manufacturing in China and the Philippines. 2008. SOMO and SwedWatch.

[75] Chan, J, Ho, C. The dark side of cyberspace: Inside the sweatshops of China's computer hardware production. 2008. WEED, SACOM, ProcureITfair.

[76] Ferus-Comelo, A. double jeopardy: Gender and migration in electronics manufacturing. In: Smith T, Sonnenfeld DA, Pellow DN, editors. Challenging the Chip: Labor Rights and Environmental Justice in the Global Electronics Industry Temple University Pres, Philadelphia, 2006.

[77] Manhart, A, Key social impacts of electronics production and WEEE-recycling in China. 2007. Freiburg, Öko-Institut e.V.

[78] SACOM. An investigative report on labour conditions of the ICT industry: Making computers in South China. 2006. Students and Scholars against Corporate Misbehaviour (SACOM).

[79] Schipper, I, de Haan, E. Hard (disk) labour: Research report on labour conditions in the Thai electronics sector. 2007. Amsterdam, Centre for Research on Multinational Corporations - SOMO.

[80] Schipper, I, de Haan, E. CSR Issues in the ICT hardware manufacturing sector. 2005. Amsterdam, Stichting Onderzoek Multinationale Ondernemingen (Centre for Research on Multinational Corporations) - SOMO.

[81] Seibert, A. Gender aspects: Production of next-generation electronics in Poland. 2007. Karat Coalition.

[82] Brigden, K, Labunska, I, Santillo, D, Walters, A. Cutting edge contamination: A study of environmental pollution during the manufacture of electronic products. 2007. Amsterdam, Greenpeace International.

[83] Byster LA, Smith T. The electronics production life cycle. From toxics to sustainability: Getting off the toxic treadmill. In: Smith T, Sonnenfeld DA, Pello DN, editors. Challenging the Chip: Labor Rights and Environmental Justice in the Global Electronics Industry Temple University Press, Philadelphia, 2006.

[84] International Labour Association. The production of electronic components for the IT industries: Changing labour force requirements in a global economy (Report for discussion at the Tripartite Meeting on the Production of Electronic Components for the IT Industries: Changing Labour Force Requirements in a Global Economy). 2007. Geneva, International Labour Association (ILO).

[85] Manhart, A, Grießhammer, R. Social impacts of the production of notebook PCs: Contribution of a product sustainability assessment (PROSA). 2006. Freiburg, Öko-Institut e.V.

[86] *www.ilo.org/global/lang--en/index.htm* (accessed September 2009)

[87] *www.sa-intl.org/, www.globalreporting.org/Home, www.csreurope.org/, and www.bsci-eu.org/* (all accessed September 2009)

[88] *www.consumersinternational.org/Templates/Internal.asp?NodeID=97579* (accessed August 2009)

[89] Rennings, K., Ziegler,A. and Rehfeld, K-M., 2004. Integrated Product Policy and Environmental Product Innovations: An Empirical Analysis, Center for European Economic Research (ZEW), Discussion Paper No. 04-071 (*http://papers.ssrn.com/sol3/papers.cfm?abstract_id=604465#*)

[90] *www.iaer.org/communications/certification.htm* (accessed July 2009)

[91] *www.epsc.ca/rvqp.html* (accessed July 2009)

[92] ITU World Telecommunication/ICT Indicators (WTI) database, *www.itu.int/net/home/index.aspx*

[93] Wright, L. Engineering Doctorate: Volume II, Part D, Section B., 86-151, 1999

[94] *www.esm.ucsb.edu/academics/courses/282/Readings/Singhal-Nokia-2005b.pdf* (accessed July 2009)

[95] Drori, GS, Jang, YS. The global digital divide: A sociological assessment of trends and causes. Social Science Computer Review 2004; 21: 144-161.

[96] Ling, R. The mobile connection: The cell phone's impact on society. San Francisco, CA: Morgan Kaufmann. 2004

[97] Scott, N, Batchelor, S, Ridley, J, Jorgensen, B. The impact of mobile phones in Africa. 2004. Glasgow, Commission for Africa. Background Papers.

[98] India: the Impact of Mobile Phones, Moving the debate forward, The Policy Paper Series, Number 9, Vodafone Group Plc, January 2009, *www.vodafone.com/publicpolicyseries* (Accessed may 2009)

[99] Hardell, L, Carlberg, M, Hansson Mild, K. Pooled analysis of two case-control studies on use of cellular and cordless telephones and the risk for malignant brain tumours diagnosed in 1997-2003. International Archives of Occupational and Environmental Health 2006;79: 630-639.

[100] Khurana, VG. Mobile Phones and Brain Tumours – A Public Health Concern, *www.brain-surgery.us/mobph.pdf* (Accessed May 2009)

[101] Williams, E, Kahhat, R, Allenby, B, Kavazanjian, E, Kim, J, Xu, M. Environmental, social, and economic implications of global reuse and recycling of personal computers. Environ. Sci. Technol. 2008; 42: 6446-6454.

[102] *http://oee.nrcan.gc.ca/residential/business/manufacturers/standby-power-fact.cfm* (accessed July 2009)

[103] *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:339:0045:0052:EN:PDF* (accessed July 2009)

[104] *http://www.energystar.gov/index.cfm?c=prod_development.prod_development_standbypower* (accessed July 2009)

[105] *www.itworld.com/green-it/58062/mobile-phone-chargers-are-energy-vampires* (accessed July 2009)

[106] Solid Waste & Recycling, Aug/Sep 2009, vol. 14, no.4. "Ring Ring!: New organization recycles cell phones," *www.solidwastemag.com*

[107] Neira, J, Favret L, Fuji, M, Miller, R, Mahdavi, S, Blass VD. End-of-life management of cell phones in the United States, April 2006 University of California [these costs estimates are based on an assumed wage of US$25 per hour including overhead, an assumed 10 minutes for manual work per phone and 2 minutes for semi-automated work per phone]. Available at *www.bren.ucsb.edu/research/documents/cellphonethesis.pdf* (Feb-2010)

[108] *http://newsgroups.derkeiler.com/Archive/Soc/soc.culture.indian/2005-11/msg00120.html* (₤964 per year in India and ₤1214 per year in China for an average of ₤1089, which is about C$2000 and assume 2000 working hours per year)

[109] *www.logisticsworld.com/logistics.htm* (accessed July 2009)

[110] De Brito, M.P., Dekker, R. Reverse Logistics – a framework, Erasmus University Rotterdam, 2002 (*www.fbk.eur.nl*)

[111] Lieberman, B. 2008. Waste by Rail – Exporting Waste off Long Island. Federation of New York Solid Waste Association, Solid Waste/Recycling Conference & Trade Show May 5th. *www.nyfederation.org/pdf2008/71VictorP.pdf*. (Accessed may 2009)

[112] Barba-Gutiérrez, Y, Adenso-Diaz, B, Hopp, M. An analysis of some environmental consequences of European electrical and electronic waste regulation. Resources Conservation and Recycling 2008; 52: 481-495.

[113] *www.cwta.ca/* (accessed May 2009)

[114] iSuppli Corporation's Consumer Trak Service at *www.isuppli.com* (accessed Feb-2010)

[115] *www.sourcewire.com/releases/rel_display.php?relid=mAiQm* (accessed Feb-2010)

[116] Eduljee, G., Arthur, D. Solid Waste Management. In: Harrison, R. editor. Pollution: Causes, Effects and Controls, Royal Society of Chemistry, U.K., 2000: 378-410

[117] Bhuie, AK, Ogunseitan, OA, Saphores, JDM, Shapiro, AA. Environmental and economic trade-offs in consumer electronic products recycling: A case study of cell phones and computers. Proceedings of the 2004 IEEE International Symposium on Electronics and the Environment. 10 May 2004 through 13 May 2004.

[118] Geyer, R., Doctori Blass, V. The economics of cell phone reuse and recycling (2009). International Journal of Advanced Manufacturing Technologies, pp. 1-11.

[119] Japanese company uses recycled cell phone parts in disposable digital cameras *www.technologygear.net/japanese-company-uses-recycled-cell-phone-parts-in-disposable-digital-cameras.html* (accessed May 2009)

[120]*www.abiresearch.com/press/1015-Recycled+Handset+Shipments+to+Exceed+100+Million+Units+in+2012* (Accessed April 2009)

[121] James, J. Low-cost computing and related ways of overcoming the global digital divide. Journal of Information Science 2001; 27: 385-392.

[122] Geyer, R., Blass, V.D. The role of displaced production for reuse and recycling: The example of cell phone end-of-life management. (Submitted to) Journal of Industrial Ecology, 2008

[123] *www.cwta.ca/CWTASite/english/provincial.html* (accessed July 2009)

[124] Chancerel, P., Meskers, C.E.M., Hageluken, C., and Rotter, V.S. Assessment of Precioous Metal Flows During Preprocessing of Waste Electrical and Electronic Equipment. Journal of Industrial Ecology. 2009.

[125]*www.environmental-expert.com/resulteacharticle.aspx?cid=341&codi=1283*
www.woodheadpublishing.com/en/book.aspx?bookID=60 (both accessed Feb-2010)

[126] Personal communication with Heinz Böni, EMPA (*www.empa.ch*), Feb-2010; also, Huisman, J. QWERTY and Eco-Efficiency Analysis on cellular phone treatment in Sweden, TU Delft, 2004

[127] Draft report comments from Eric Johnson (EUROMETREC), Eric Harris (ISRI), Ross Bartley (BIR) in direct correspondence with Henrik Harjula (OECD), Jan-2010.

[128] Cobbing, M. Toxic tech: Not in our backyard uncovering the hidden flows of e-waste, Greenpeace, Feb-2008

[129] Dowa Eco-Systems Co., *www.dowa-eco.co.jp/en/recycle.html*; Boliden, *www.boliden.com/www/en/bolidenen.nsf/(WebPagesByID)/CD329E0C78048C60C1256F1E00517758/$file/raw_*

material_1.pdf; Horne Smelter+CCR, *www.xstrata.com/operation/ccr/*; Aurubis (Norddeutsche Affinerie), *www.aurubis.com/en/home/*; Umicore, *www.umicore.com/en/* (all accessed Feb or Apr 2009)

[130] *www.basel.int/centers/centers.html* (accessed June 2009)

[131] Cui, J, Zhang, L. Metallurgical recovery of metals from electronic waste: A review. Journal of Hazardous Materials 2008; 158: 228-256.

[132] VM Group, The white book, 2008, Vortis (Merchant Banking)

[133] Krikke, J. Recycling e-waste: The sky is the limit. IT Professional 2008; 10: 50-55.

[134] Rochat, D, Hagelüken, C, Keller, M, Widmer, R. Optimal Recycling for Printed Wiring Boards (PWBs) in India. Hilty, L. M. Edelmann X. Ruf A. eds. R'07 World Congress - Recovery of Materials and Energy for Resource Efficiency . Empa Materials Science and Technology. 2007.

[135] Cui, J, Zhang, L. Metallurgical recovery of metals from electronic waste: A review. Journal of Hazardous Materials 2008; 158: 228-256.

[136] Hagelüken, C. Improving metal returns and eco-efficiency in electronics recycling - A holistic approach for interface optimisation between pre-processing and integrated metals smelting and refining. 2006, 218-223. 2006. Scottsdale, AZ. 2006 IEEE International Symposium on Electronics and the Environment. 8 May 2006 through 11 May 2006.

[137] Leung, AOW, Duzgoren-Aydin, NS, Cheung, KC, Wong, MH. Heavy metal concentrations of surface dust from e-waste recycling and its human health implications in southeast China. Environ. Sci. Technol. 2008; 42: 2674-2680.

[138] Ha, NN, Agusa, T, Ramu, K, Tu, NPC, Murata, S, Bulbule, KA, Parthasaraty, P, Takahashi, S, Subramanian, A, Tanabe, S. Contamination by trace elements at e-waste recycling sites in Bangalore, India. Chemosphere Article in Press.

[139] Allsopp, M, Santillo, D, Johnston, P. Environmental and human health concerns in the processing of electrical and electronic waste. 2006. Exeter, Greenpeace Research Laboratories.

[140] Brigden, K, Labunska, I, Santillo, D, Allsopp, M. Recycling of electronics wastes in China and India: Workplace and environmental contamination. 2005. Amsterdam, Greenpeace International.

[141] Jackson, AS, Schuman, A, Dayaneni, G. Toxic sweatshops: How UNICOR prison recycling harms workers, Communities, the Environment, and the Recycling Industry. 2006. Center for Environmental Health, Prison Activist Resource Center, Silicon Valley Toxics Coalition, Computer TakeBack Campaign.

[142] Williams, E., Kahhat, R., Allenby, B., Kavazanjian, E., Kim, J., & Xu, M. (2008). Environmental, Social, and Economic Implications of Global Reuse and Recycling of Personal Computers. Environ. Sci. Technol:2008; 41: 6446-6454.

[143] *www.wasteonline.org.uk/resources/WasteWatch/JobsFromWaste_files/page7.html*, and *www.ilsr.org/recycling/recyclingmeansbusiness.html*

[144] *http://info.goldavenue.com/Info_site/in_glos/in_glos_tollrefining.html* (accessed August 2009)

[145] Personal communication with Christian Hagelüken, Umicore, (Feb-2010)

[146] Most, Eric. Calling All Cell Phones: Collection, Reuse and recycling Programs in the US, INFORM Inc., 2003

[147] US EPA, Electronics Waste Management in the United States: Approach 1, July 2008. EPA530-R-08-009, *www.epa.gov/waste/conserve/materials/ecycling/manage.htm*

[148] Lincoln, JD, Ogunseitan, OA, Shapiro, AA, Saphores, JDM. Leaching assessments of hazardous materials in cellular telephones. Environ. Sci. Technol. 2007; 41: 2572-2578. and, Stephen E. Musson, Kevin N. Vann, Yong-Chul Jang, Sarvesh Mutha, Aaron Jordan, Brian Pearson, and Timothy G. Townsend, 2006, RCRA Toxicity Characterization of Discarded Electronic Devices, Environmental Science & Technology, 40, pp 2721-2726

[149] Splavins, E, Dubey, B, Townsend, T. Impact of electronic waste disposal on lead concentrations in landfill leachate. Environ. Sci. Technol. 2008; 42: 7452-7458.

[150] International Precious Metals Institute. Environmentally sound management – used mobile telephones. *http://ipmi.org/pdf/IPMI_Guidance_Used_Mobile_Phones.pdf* (Accessed May 2009)

[151] Owens, CV, Lambright, C, Bobseine, K, Ryan, B, Gray, LE, Gullett, BK, Wilson, VS. Identification of estrogenic compounds emitted from the combustion of computer printed circuit boards in electronic waste. Environ. Sci. Technol. 2007;41: 8506-8511.

[152] Landfill Mining: Preserving Resources through Integrated Sustainable Management of Waste, Technical Brief from the World Resource Foundation, (no date), *www.enviroalternatives.com/landfill.html*

[153] Fisher, H. & Findlay, DM. Exploring the Economics of Mining Landfills, Waste Age (trade journal), 1995 *http://wasteage.com/mag/waste_exploring_economics_mining/*

[154] *www.nokia.com/environment/our-responsibility/substance-and-material-management* (accessed June 2009)

[155] ICF Consulting. Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions: 2005 Update, Environment Canada and Natural Resources Canada, *www.nrcan-rncan.gc.ca/mms-smm/busi-indu/rad-rad/rad-gge-eng.htm#d*

[156] *www.stanford.edu/group/scforum/Introduction/Background/*

[157] Zsidisin, G.A. and S.P. Siferd, 2001. "Environmental purchasing: A framework for theory development." European Journal of Purchasing & Supply Management, 7: 61-73 (cited by Hagelaar, G. and J. van der Vorst, 2001. "Environmental Supply Chain Management: using Life Cycle Assessment to structure supply chains". IAMA paper, Sydney, Australia, 2001)

[158] *www.marcbowles.com/* (accessed Feb-2010)

[159] Five Winds International. Eco-efficiency and materials. 2001. International Council on Metals and the Environment.

[160] *www.icmm.com* (accessed July 2009)

[161] *www.mining.ca* (accessed July 2009)

[162] *www.minerals.org.au/environment* (accessed July 2009)

[163] *www.nma.org/issues/environment/sustainable_development.asp* (accessed July 2009)

[164] *http://ecoble.com/2009/01/06/green-cell-phone/* (accessed July 2009)