



**OECD GLOBAL FORUM ON  
ENVIRONMENT**

**Focusing on**

**SUSTAINABLE MATERIALS  
MANAGEMENT**

25-27 October 2010, Mechelen, Belgium

**Summary Paper 1:**

**Summary of SMM Case Studies**

**Working Document**

OECD Environment Directorate, OECD, 2010

## **NOTE FROM THE SECRETARIAT**

This document summarises the four case studies commissioned by OECD on aspects of life cycle management of priority materials, namely: critical metals, wood fibres, aluminium, and plastics.

This summary paper has been prepared by John Atherton from the International Council on Mining and Metals (ICMM), to support the discussion of session 1 of the Global Forum on “Good SMM Practices in Priority Materials”.

The opinions expressed in this paper are the sole responsibility of the author and do not necessarily reflect those of the OECD or the governments of its member countries.

## Table of Contents

NOTE FROM THE SECRETARIAT .....	2
SUMMARY DOCUMENT ON SMM CASE STUDIES .....	4
INTRODUCTION.....	4
Purpose of Document.....	4
SUMMARY OF CASE STUDIES.....	4
1. Critical Metals .....	4
Resource Flows .....	4
Life Cycle Perspective .....	6
Policy Measures .....	6
Producer and Consumer Behaviour.....	7
2. Wood Fibre.....	7
Resource Flows .....	7
Life Cycle Perspective .....	8
Policy Measures .....	8
Producer and Consumer Behaviour.....	9
3. Aluminium.....	10
Resource Flows .....	10
Life Cycle Perspective .....	11
4. Plastics .....	11
Resource flows .....	11
Life Cycle Perspective .....	12
Policy Measures .....	13
Producer and Consumer Behaviour.....	13
DISCUSSION AND CONCLUSION .....	14
Discussion.....	14
1) Interconnections between SMM and other policy areas.....	14
2) Priority life cycle stages .....	14
3) Geographic flows of materials.....	14
Conclusion .....	15

## SUMMARY DOCUMENT ON SMM CASE STUDIES

### INTRODUCTION

#### **Purpose of Document**

This document summarises case studies commissioned by OECD on aspects of life cycle management of priority materials, namely: critical metals, wood fibres, aluminium, and plastics.

This summary document is oriented around the “Key Questions” on the case studies that have been prepared by the SMM Steering Group. It is intended to assist policymakers in the development of effective Sustainable Material Management (SMM) policies. In particular, the summary document is directed towards policymakers attending the OECD Global Forum on Environment scheduled for 25-27 October 2010 in Mechelen, Belgium, at which the main focus will be on “policies for implementing SMM in priority sectors, materials or products.”

The critical metals study was prepared by the Government of Canada; the aluminium study by the U.S. Geological Survey; the wood fibres study by ICF International; and the plastics study by Plastics Europe Deutschland. This summary document was prepared by the International Council on Mining and Metals (ICMM) and a consultancy company, Five Winds International. The information presented in this document summarizes the information and opinions presented in the case studies, and do not necessarily reflect the position of ICMM or Five Winds International.

### SUMMARY OF CASE STUDIES

#### **1. Critical Metals**

This case study focused on the application of critical metals in mobile phones. For practical reasons, the scope of the case study was limited to a short list of four critical metals that are (a) exposed to potential supply risk, (b) subject to supply restriction and (c) found in mobile phones. The four selected critical metals were: antimony, beryllium, palladium, and platinum.

#### Resource Flows

##### *What are the major stages in the life cycle of this material or product?*

The stages in the life cycle of mobile phone are: (1) raw material extraction, (2) component manufacture and assembly, (3) use, and (4) end-of-life (EOL) comprised of (a) refurbishing/reuse, (b) material recovery – pyrometallurgy, (c) material recovery – informal, and (d) disposal.

***Roughly what amounts of resources flow through each of the major life cycle stages?***

The amounts of resources that flow through each of the major life cycle stages are shown in the table below. Of particular note, it is estimated that only 2.5% of mobile phones at end-of-life is recycled in an environmentally sound management (ESM) compliant facility. These facilities efficiently recover palladium and platinum. However, antimony is recovered with variable efficiencies and beryllium is not recovered.

	Reserves (tons)	Raw Material Extraction (tons/year)	Component Manufacture and Assembly (tons/year)	Use	End-of-life			
					Reuse/ Refurbished	Material Recovery (pyro)	Material Recovery (informal)	Disposal (Landfill or incineration)
Antimony	2,100,000	180,000	84	Some data available for Canada	Data not available	2.5%	Data not available	Data not available
Beryllium	80,000	190	7.1					
Palladium	75,000	219	12.1					
Platinum	25,000	213	0.3					
<i>Data Quality</i>	<i>Estimated</i>	<i>Reported</i>	<i>Estimated</i>	<i>Modeled</i>	<i>n/a</i>	<i>Estimated</i>	<i>n/a</i>	<i>n/a</i>

In addition to the material flow through life cycle stages, the geographic flow of critical metals was a very important theme of the case study. Over 80% of the mining production of the critical metals analyzed (apart from beryllium) takes place in non-OECD countries. For example, China supplies 87% of the world’s supply of antimony.

***Given current government policies, how might flows be expected to change in the future?***

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.

Despite current legislation and recycling efforts, recycling rates are expected to remain low due to the global trade of end-of-life mobile phones. Regulatory and enforcement infrastructure is currently established to reduce environmental and social impacts of informal recycling that tend to be located in developing countries. However, the economic imperative will probably continue to provide incentive for illegal trade.

***Can the material cycle be sustained in the long term? To what extent is natural capital preserved?***

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. 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.

## Life Cycle Perspective

### *At what stages do the biggest impacts to sustainability occur?*

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.

The predominant environmental impacts (*e.g.* GHG emissions) in the life cycle of consumer electronic devices occur at the **manufacturing** stage. This is particularly the case for mobile phones since the miniaturization and the computer power required to carry their increased functionality means that the energy inputs are more intensive than mining and raw material processing activities.

The **mining** of raw materials, and **manufacturing** and **end-of-life** stages of consumer electronic devices all have significant social impacts on the workforce and on local communities. At all three of these stages, the social issues are related to the geo-political situation where these stages take place. At the mining stage, some social concerns focus on a specific mineral sourced from a specific region (*e.g.* coltan mineral mining in the Democratic Republic of Congo), while others focus on the performance of a specific company. At the manufacturing and end-of-life stages, the social concerns are largely about labour conditions in Asia and developing countries.

## Policy Measures

### *What policy measures have been taken or can be taken to stimulate sustainable environmental, economic and social outcomes?*

#### Raw Material Extraction and Processing

- 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 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.
- The social 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 significant progress.

#### Design

- When a device is first conceptualized, it is becoming increasingly recognised that the designer should take recycling into consideration. Insofar as policy-making is concerned, the impetus for encouraging design for environment (DfE) has tended to lie with the introduction of user pay principles and extended producer responsibility.

#### Product Use

- The European Integrated Product Policy 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.

#### End-of-Life

- Where recovery rates remain low, it is possible that a deposit program for mobile phones would boost their capture. Another 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 extended producer responsibility 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.

#### Producer and Consumer Behaviour

*To what extent are different actors in society engaged in taking up responsibilities for sustainable outcomes?*

The promotion of SMM concepts by government may help the marketplace to recognise 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.

## 2. Wood Fibre

This case study focused on opportunities for the pulp and paper industry to reduce energy use, greenhouse gas (GHG) emissions and water use throughout the fibre product life cycle.

#### Resource Flows

*What are the major stages in the life cycle of this material or product?*

The stages in the life cycle of wood fibre are: (1) forest management, (2) timber extraction, (3) virgin paper processing, (4) use, (5) end-of-life (EOL) comprised of (a) recycling, (b) incineration, or (c) landfilling.

*Roughly what amounts of resources flow through each of the major life cycle stages?*

The amounts of resources that flow through each of the major life cycle stages are shown in the table below.

	Forest Management	Timber Extraction (tons/year)	Virgin Paper Processing (tons/year)	Use (tons/year)	End-of-life		
					Recycling (tons/year)	Incineration	Landfilling
Wood fibre	Data not available	285 million	176 million	355 million	159 million	20% in US	80% in US
<i>Data Quality</i>	<i>n/a</i>	<i>Estimated</i>	<i>Reported*</i>	<i>Reported*</i>	<i>Reported*</i>	<i>Some regional data available</i>	<i>Some regional data available</i>

\* 2004 data

### *Given current government policies, how might flows be expected to change in the future?*

The market for paper and board is projected to grow globally at 2.3% per year to 2030, with particularly rapid increases in developing and emerging economies. Currently, most of the traded wood products, including pulp, paper, and recovered paper, are travelling from Europe and North America into China. In the future, there is an expected shift in production capacity from the traditional large producers (*i.e.* North America and Western Europe) to emerging economies such as China, India and Latin America.

### *Can the material cycle be sustained in the long term? To what extent is natural capital preserved?*

There is a concern that deforestation and illegal logging in developing nations is outpacing the regeneration capacity of their forests. As timber is a globally traded commodity, localised deforestation does not necessarily impact the global “material cycle” of wood fibre.

#### Life Cycle Perspective

##### *At what stages do the biggest impacts to sustainability occur?*

- **Virgin paper processing:** The pulping stage either via chemical or mechanical processes and the papermaking stage use the most energy across the life cycle. Chemical pulping uses more energy and water than mechanical pulping per tonne of paper. The bleaching stage of chemical pulping involves the largest source of emissions to water, including organic substances, chlorinated organic substances, phosphorous and metals. Using best technology and management practices in virgin paper processing would significantly reduce overall energy and water use.
- **End-of-life:** There are three main pathways for end-of-life paper including recycling, incineration (combustion), and landfilling. Associated with each pathway are various profiles of energy and GHG emissions. Recycling paper results in the largest GHG savings followed by incineration with energy recovery. The inclusion of the forest carbon sequestration benefit clearly drives the majority of the GHG benefits. Increasing paper recycling and use of recovered paper in production would result in significant energy and GHG savings.

#### Policy Measures

##### *What policy measures have been taken or can be taken to stimulate sustainable environmental, economic and social outcomes?*

- **Promote sustainable forestry management (SFM):** One of the most important focus areas is to promote sustainable forestry management (SFM) both within OECD and particularly with developing nations. This can be done through certification systems and through support by OECD member countries. Independent third-party certification and effective enforcement capabilities are crucial to establishing credibility of SFM sourced paper products.
  - Drivers
    - Inclusion of environmental benefits when evaluating the costs and benefits
    - Global regulations and policy frameworks, particularly in regard to climate change
    - Increased consumer awareness
  - Barriers
    - Weak governance
    - Imbalanced resources in developing countries relative to OECD countries

- **Modernise old equipment:** Interventions that modernise older equipment and speed up the rate of capital turnover can be particularly effective, particularly at the pulping and papermaking stages where energy use, GHG emissions and water use are high.
  - Drivers
    - High energy demand of industry and large potential efficiency gains if realised at a commercial scale
    - Cost savings achieved by reducing high fossil fuel costs
  - Barriers
    - Slow rates of capital infrastructure turnover
    - High costs of capital investments
    - Lack of data and information sharing
  
- **Set recycling targets:** The European Union mandated under the Directive on Packaging and Packaging Waste a minimum recycling target for paper and board of 60% by weight. Further, the European paper industry adopted a voluntary commitment to achieve 66% recycling rate. This industry commitment includes not only a recycling rate target but provides guidance to fourteen industry sectors along the paper value chain to ensure higher recyclability of paper at the end-of-life. As a result of these government and industry targets, European recycling rates are as high as 64.5% compared to 53% in the United States.
  - Drivers
    - Cost savings from using recovered fibres to offset production of virgin fibres
    - Substantial gains available using existing technologies / practices to recover paper
  - Barriers
    - Secondary market price volatility
    - Economic trade-offs between maximizing paper recovery and the quality of paper that is recovered

### Producer and Consumer Behaviour

#### *To what extent are different actors in society engaged in taking up responsibilities for sustainable outcomes?*

Many of the drivers of deforestation lie outside the influence of the paper industry. Factors such as expanding agriculture and livestock production, infrastructure development, population growth, urbanization, market distortions, and global demand for agricultural products and biofuels underlie most deforestation and its associated impacts on sustainability. As such, any government policy on the Sustainable Material Management (SMM) of wood fibres should be considered through inter-sectoral engagement mechanisms that include these external factors.

### 3. Aluminium

This case study on aluminium addressed the Working Group questions pertaining to Resource Flows and Life Cycle Perspective. As the case study did not address the questions related to Policy Measures and Producer and Consumer Behaviour, responses to these questions are not included in this summary document.

The paper uses two models of economic development to examine future aluminum consumption. The first forecasts future amounts of aluminum that will be consumed on a country-by-country and global basis from expected rates of economic growth. The second model examines changing end uses of aluminum within countries as income increases. The changes in end-uses are then used to examine likely flows of post-consumer scrap.

#### Resource Flows

##### *What are the major stages in the life cycle of this material or product?*

The stages in the life cycle of aluminium are: (1) bauxite mining, (2) alumina refining, (3) aluminium smelting, (4) fabrication, (5) use, and (6) end-of-life (EOL) comprised of (a) recycling or (b) landfilling.

##### *Roughly what amounts of resources flow through each of the major life cycle stages?*

The amounts of resources that flow through each of the major life cycle stages are shown in the table below.

	Bauxite Mining (tons/year)	Alumina Refining (tons/year)	Aluminum Smelting (tons/year)	Fabrication - output (tons/year)	Use - net additions (tons/year)	End-of-life	
						Recycling (tons/year)	Landfilling (tons/year)
Aluminium	179.5 million	65.5 million	68.8 million	40.4 million	24.4 million	7.8 million	3.5 million
<i>Data Quality</i>	<i>Reported*</i>	<i>Reported*</i>	<i>Reported*</i>	<i>Reported*</i>	<i>Reported*</i>	<i>Reported*</i>	<i>Reported*</i>

\* 2006 data

##### *Given current government policies, how might flows be expected to change in the future?*

By 2025, global aluminium demand is likely to double that of the base year (2006) for the case study. Studies have shown that industrial aluminium use is directly related to a country's average income. Therefore, increased aluminium use is particularly expected in the emerging economies of China, Russia, Brazil and India.

Aluminium smelting is electricity intensive. For this reason, changes in the price and availability of electricity result in the location of new smelters in areas with cheaper and more readily available electricity supply. For example, the availability of abundant supplies of natural gas has led to the development of significant aluminium smelters in Bahrain and the United Arab Emirates in recent years. New aluminium smelters are also being built in Iceland based upon abundant electricity generated from hydropower and geothermal power.

The imposition of carbon taxes or carbon emissions pricing could over time significantly affect the location of aluminum smelters as countries move facilities to countries with abundant, cheaper electricity.

### *Can the material cycle be sustained in the long term? To what extent is natural capital preserved?*

Nearly 80% of aluminium is used in the building, transportation, and engineering sectors. The products within these sectors have life spans of over 10 years. With the majority of aluminium-containing products still in use, significant amounts of recycled aluminium from post consumer scrap are not likely to appear until sometime between 2020 and 2025. The increased demand for aluminium will largely have to be met by increased production of primary aluminium rather than by recycled aluminium.

Society's continual reliance on primary aluminium means that energy price and GHG reduction policy will continue to exert great influence on the technology evolution and the economy of the sector.

### Life Cycle Perspective

#### *At what stages do the biggest impacts to sustainability occur?*

- **Aluminum Smelting:** The largest source of GHG emissions is the indirect emissions from grid electricity during the smelting phase. Aluminium smelting also directly emits carbon dioxide and two kinds of perfluorocarbon gases (PFCs). PFCs are of particular concern because they are a group of potent greenhouse gases. It has been estimated that 1 ton of CF<sub>4</sub> has the equivalent global warming potential (GWP) of 6,500 tons of CO<sub>2</sub>, and that 1 ton of C<sub>2</sub>F<sub>6</sub> has the equivalent GWP of 9,200 tons of CO<sub>2</sub>.
- **Bauxite Mining:** Approximately 1.5 to 2 tons of bauxite residue (also known as red mud) are generated per ton of alumina produced. While a number of potential uses have been suggested for the solid waste, currently there are no economically viable and environmentally acceptable solutions for effective use of the large volume of residue generated. Red mud is usually disposed of in a landfill.

## **4. Plastics**

This case study focused on the European plastic industry produced from fossil fuel based raw materials, and opportunities for increasing recycling and energy recovery rates.

### Resource flows

#### *What are the major stages in the life cycle of this material or product?*

The stages in the life cycle of plastics are: (1) production, (2) processing, (3) use, and (4) end-of-life (EOL) comprised of (a) mechanical recycling, (b) feedstock recycling, (c) energy recovery, and (d) disposal.

Mechanical recycling is the mechanical grinding down and sorting of used plastics directly back into re-processable granules. The chemical structure remains almost unchanged. The small ground-down plastic pieces are cleaned and separated into different grades. Mechanical recycling is an economically viable option when the plastic recovered is clean and of a single type.

Feedstock recycling is the breaking down of plastics into its chemical components from which new plastics or other chemicals can be manufactured. Feedstock recycling is an economically viable solution where lots of different plastics are mixed together or where the material is contaminated with other substances.

Energy recovery is the combustion of plastic waste while simultaneously using the energy for generating electricity or steam or for providing process heat. Energy recovery is particularly suitable for mixed or contaminated fractions of plastic waste.

***Roughly what amounts of resources flow through each of the major life cycle stages?***

The amounts of resources that flow through each of the major life cycle stages are shown in the table below.

	Production (tons/year)	Processing (tons/year)	Use (tons/year)	End-of-life			
				Material Recycling (tons/year)	Feedstock Recycling (tons/year)	Energy Recovery (tons/year)	Landfilling (tons/year)
Plastics (in Europe)	62 million	52.5 million	Data not available	5 million		7.2 million	12.4 million
<i>Data Quality</i>	<i>Reported*</i>	<i>Reported*</i>	<i>n/a</i>	<i>Reported*</i>		<i>Reported*</i>	<i>Reported*</i>

\* 2007 data

***Given current government policies, how might flows be expected to change in the future?***

Since 1950, the global rise in plastics consumption has been, on average, 9% per year. An analysis of the plastics consumption per capita shows that this has now risen to around 100 kg per inhabitant in the NAFTA (North American Free Trade Agreement) countries and Western Europe, and has the potential to grow to 140 kg per person by 2015. The greatest potential for growth is in the fast developing parts of Asia, where present per capita consumption is rather low, about 20 kg per capita (except in Japan).

***Can the material cycle be sustained in the long term? To what extent is natural capital preserved?***

Plastics are derived from non-renewable fossil fuel resources. Around 4 – 6 % of fossil fuels are used in the manufacture of plastics. The challenge of a sustainable material cycle for plastics is therefore directly tied to the challenge of sustainable energy supply.

Life Cycle Perspective

***At what stages do the biggest impacts to sustainability occur?***

The case study focused on the sustainability impacts of various plastic waste recovery options at the end-of-life stage of plastic products. The conclusion of the LCA was that no recovery process is superior to any other. Rather, this decision depends on the source and type of waste, the availability of recycling infrastructure, and the market for recycled materials.

The case study also referred to examples of how plastics contribute to energy savings during a product’s use phase, e.g. by reducing fuel consumption of cars, by decreasing the overweight of the vehicle or by considerably reducing the energy required for heating as a result of effective insulation of buildings.

## Policy Measures

*What policy measures have been taken or can be taken to stimulate sustainable environmental, economic and social outcomes?*

Material and energy recovery of plastic waste varies widely from country to country. High recovery rates are particularly evident in countries where landfilling of high calorific waste is largely restricted or totally banned, such as in Switzerland, Germany, Sweden and Denmark. For example, a diversion rate of almost 96% was reached in 2007 after a ban on landfilling waste with a high calorific value came into force in Germany on 1 June 2005.

## Producer and Consumer Behaviour

*To what extent are different actors in society engaged in taking up responsibilities for sustainable outcomes?*

The case study suggests that consumer behaviour is not a significant roadblock for plastics recycling, given the high diversion rates in jurisdictions with strict landfill bans.

## DISCUSSION AND CONCLUSION

### Discussion

The case studies on critical metals, wood fibres, aluminium, and plastics revealed some interesting commonalities, as well as some differences. The discussion below briefly describes how the case studies compare with respect to their interconnections between SMM and other policy areas; priority life cycle stages; and geographic flows of materials.

#### 1) Interconnections between SMM and other policy areas

Each of the case studies illustrated interconnections between sustainable materials management (SMM) and other OECD policy areas. These policy areas differed depending on the material:

- Critical metals: SMM of critical metals is closely connected to innovation and the transboundary movement of hazardous wastes.
- Wood fibres: SMM of wood fibres is closely connected to several policy areas, most notably climate change, but also agriculture, population growth, and urbanization.
- Aluminum: SMM of aluminium is closely connected to energy and climate change policy.
- Plastics: SMM of plastics is also closely connected to energy and climate change policy.

#### 2) Priority life cycle stages

The life cycle stages at which the biggest impacts to sustainability occur differ by material. For wood fibres, the biggest impacts to sustainability take place at the beginning of its life cycle, in the management of the resource stock (*i.e.* sustainable forest management). For plastics and aluminium, the biggest impacts to sustainability take place in the production and end-of-life stages of the product. For the critical metals the biggest impacts to sustainability take place at the design and end-of-life stages.

#### 3) Geographic flows of materials

For three of the four case studies, the discussion on resource flow and technology transfer from country to country was as important as the discussion on resource flow through life cycle stages.

- Critical metals: The criticality of specialized metals depends on several factors, including its level of dependence on a limited number of sometimes politically unstable countries. SMM policy decisions regarding on critical metals therefore need to take the issue of material security – the access of industries, companies and countries to raw materials to ensure social, economic and military sufficiency, into account.
- Wood fibres: In the future, there is an expected shift in timber extraction and paper processing capacity from the traditional OECD countries to emerging markets such as China, India and Latin

America. With the shift in production capacity, it will important for OECD countries to support the promotion of sustainable forestry management (SFM) and implementation of best technology and management practices with developing countries.

- Aluminium: Primary aluminium production is electricity intensive. Changes in the price and availability of electricity result in the location of new aluminium smelters in areas with cheaper and more readily available electricity supply, such as the Middle East (Bahrain and UAE) and Iceland.

The case studies demonstrate that developing countries are not only a large source of raw materials. Their role in production, use, and end-of-life management of materials are increasing as their economies develop. This shift has some important implications:

- (1) Assumptions that make sense within a defined system can be wrong once system boundaries are crossed. *E.g.* Illegal trade of end-of-life mobile phones.
- (2) Relative to OECD countries, developing countries have fewer resources and capacity to promote and enforce SMM-based policies. *E.g.* Ability to enforce Sustainable Forest Management practices.
- (3) Increased need for cross-border cooperation and coordination. *E.g.* Speed up the rate of capital turnover in developing countries to reduce global GHG emissions.

## Conclusion

In conclusion, the case studies on priority materials provide detailed examples of the need for creative, far-sighted and integrated solutions using life cycle thinking to reduce the negative environmental impacts of materials.

The case studies demonstrate how SMM is interdependent on a wide range of other policy areas, ranging from climate change, to the transboundary movement of hazardous wastes, to urbanization. The importance of other policy areas varies by the material under consideration. SMM therefore requires policymakers to work across policy areas. Such collaboration should be conducted in a targeted manner that is specific to the particular material.

The priority life cycle stages at which the biggest impacts to sustainability occur also differ by material. For wood fibres, the priority life cycle stage is management of the resource stock. For plastics and aluminium, the priority life cycle stages are the raw material production and end-of-life stages. For critical metals, the priority life cycle stages are the design and end-of-life stages of the material. These differences in priority life cycle stages should therefore be reflected in the strategic approaches for the sustainable management of each material.

Finally, the case studies demonstrate that developing countries are not only a large source of raw materials. Their role in production, use, and end-of-life management of materials has increased, and in turn, so has the need for cross-border cooperation and coordination.