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IRON, STEEL AND ALUMINIUM IN THE UK: MATERIAL FLOWS AND THEIR ECONOMIC DIMENSIONS

Final Project Report, March 2004

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Steering Committee

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Any remaining errors in the report are the sole responsibility of the authors. Opinions expressed are also those of the authors and not necessarily those of the organisations and individuals mentioned here.

EXECUTIVE SUMMARY

1. Introduction

Economic activity is associated with resource flows related to the extraction, production, consumption or use, and disposal of materials and products. Information on the quantities of these flows, relating to specific materials, economic sectors, or geographic areas, is vital for sustainable resource management, particularly at the end-of-life stage where resources become wastes. In light of rising waste disposal costs and other increasingly stringent environmental legislation, the management of resource flows is gaining importance both at the level of individual companies and industries, and as a policy issue.

The *Mass Balance* suite of Biffaward projects, coordinated by the Sustainable Economy Programme of Forum for the Future, has generated data on resource flows through the UK economy, in a common framework to maximise the usefulness of the data (Linstead and Ekins, 2001). The projects rely on the mass balance principle, grounded in thermodynamic laws, that the total mass of inputs must equal the total mass of outputs, in some form. This principle of balance helps uncover hidden flows in the economy, such as in the form of emissions to air or stocks of materials, for example stocks of a material contained in a landfill.

This report is the joint report of two separate projects funded under the Biffaward Mass Balance programme[1]: the *Material Flows of Iron/Steel and Aluminium in the UK*, undertaken at the Centre for Environmental Strategy at the University of Surrey; and the *Economic Dimensions of Material Flows of Iron/Steel and Aluminium in the UK*, undertaken at the Policy Studies Institute. In practice, the two projects functioned in many respects as one project with two distinct parts, and there was a high level of mutually beneficial collaboration between the project partners. Throughout the report, the former project is referred to as the material flow analysis (MFA), and the latter project as the value chain analysis (VCA).

Steel and aluminium are two of the commonest structural metals in the UK, and are produced and exist in society in great quantities. The concept of sustainable development presents particular challenges for primary industries such as these, because environmental sustainability requires the conservation and prudent use of non-renewable resources and the management of environmentally damaging impacts associated with the extraction and processing of these resources. Because of the value of steel and aluminium, well-established techniques and infrastructure have been developed to recycle these metals, with significant savings in energy and material inputs and a reduction in environmental impacts as a result.

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[1] The projects were funded under the Landfill Tax Credit Scheme. The authors would gratefully acknowledge the financial and in-kind support for the project received from Alcan, the Aluminium Federation, Corus, the European Aluminium Association, and the Iron and Steel Statistics Bureau.

2. Project Objectives

The purpose of the MFA has been to provide a reliable set of time series data on the flows and stocks of iron/steel and aluminium as they pass through the UK economy. The MFA aimed to collect and synthesise yearly data, going back for iron/steel to the 1960s and for aluminium to the 1950s, on the material flows associated with the production, use, recovery and reuse of iron/steel and aluminium in the UK. This includes data on primary and secondary raw materials; finished materials such as iron and steel products and semi-finished aluminium products; metal content in final goods containing steel and aluminium; and imports and exports of these materials.

In addition to these material flows, the MFA also aimed to use a time series approach to model the stocks (i.e. iron/steel and aluminium contained in goods) in use and hence to estimate the end-of-life (EOL) scrap arisings. Iron/steel and aluminium exist in a range of goods with different lengths of service lives, such as packaging materials, vehicles, or buildings – some of which can remain in use for several decades: the modelling approach has to allow for the distribution of service lives.

To enhance the policy relevance of the MFA, a parallel VCA aimed to relate the material flows to economic variables, as this consideration of economic dimensions sheds further light on such concepts as resource productivity and sustainable resource management. The purpose of the VCA was to provide a methodology for investigating the economic values associated with the current material flows and stocks of steel and aluminium in the UK; to map the value chain corresponding to the material flows; and to examine how these values relate to resource productivity and recovery.

3. MFA Methodology

The principle behind MFA is the first law of thermodynamics on the conservation of matter: that matter, i.e. mass or energy, is neither created nor destroyed by any physical transformation (production or consumption) processes. This material balance principle provides a logical basis for physical bookkeeping of the economy-environment relationship and for the consistent and comprehensive recording of inputs, outputs and material accumulation.

Unlike other MFA studies that use a simple “current account” approach to mass balance, and therefore only account for one or two years’ flows, this MFA features a time series approach which applies the theory of residence time distributions to account for material stocks, primarily of goods in use. This time series feature will therefore help understand how the significant stocks of these metals in use have been built up historically. For upstream material flows, data are assembled from available industrial and governmental statistics on a yearly basis. For downstream material flows (i.e. iron/steel and aluminium content in goods), the time series data is disaggregated into different broad categories of applications (e.g. construction, transport and packaging).

By matching the time series to the predictions of a dynamic MFA model, estimates are obtained for the quantities of these metals in current use in each of the categories.

Furthermore, different life-span distributions have been applied to describe each broad category of goods that enter use in the UK to infer estimates of available EOL waste of these metals. This enables the sensitivity of scrap arisings to the distribution of service lives to be explored, for the first time in MFA. It also gives a way of systematically investigating the level of closure of the data describing the flows of iron/steel and aluminium in the UK.

4. MFA Findings

Iron and steel

The iron/steel time series MFA found that the ultimate demand of iron and steel (i.e iron/steel contained in goods and applications) has been fairly stable over the years. In terms of sources of the flows, currently over half of the goods containing iron and steel needed for the domestic market are imported. The significance of imported goods in meeting domestic needs for iron and steel does not mean low domestic production. Around half of the upstream production (i.e. producing iron/steel products and goods containing the metal) in the iron/steel supply chain is exported.

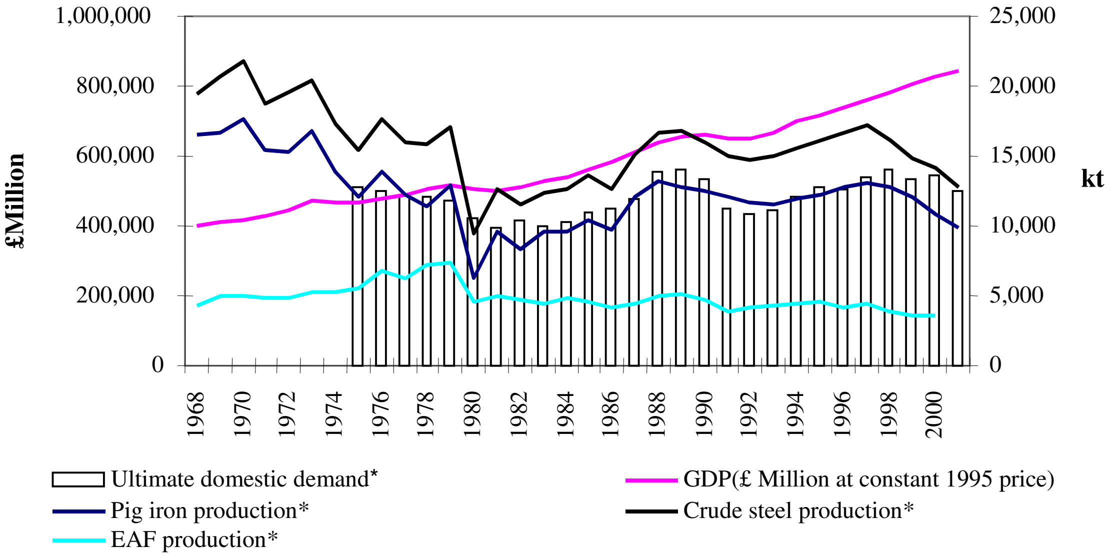
When comparing the current and past situations in the upstream iron and steel supply chain, there was higher production with relatively smaller exports and imports in the 1960s and 1970s. This implies that domestic production was able to meet most downstream domestic demand. However, the upstream iron/steel supply chain currently imports around 40-50% of iron/steel products to support demand in downstream goods manufacturing. Up to 40% of goods containing iron and steel produced in the UK are exported to help other countries satisfy their domestic demand for these goods. Thus there have been significant shifts in the role of domestic production and trade in the supply chain over the years.

Accompanying these dynamic material flows are stocks of different material categories including both manufacturing and industrial stocks and stocks of products in use, together with prompt and end-of-life (EOL) scrap arisings. The study inferred that there are currently about eleven million tonnes of prompt and EOL iron and steel scrap arisings. About 70% of this scrap is recovered, then either reused/recycled domestically or exported. Around 30% is lost from the economy, of which two thirds ends up in landfill.

Over the past 30 years, the UK has experienced declining secondary iron and steel production. Currently the electric arc furnace (EAF) steel making route accounts for 25% of total crude steel output in this country whilst it used to contribute 35-40% in the 1970s and 1980s. This change has been associated with increasing exports of scrap; currently more than half of the recovered iron and steel scrap is exported.

Figure ES.1 shows the decline in both pig iron and crude steel production between 1968 and 2001 in comparison with the increase in GDP. Pig iron and crude steel production decreased by an annual rate of 1.5% and 1.22%, while GDP grew by an average annual 2.22% over the past 34 years. Figure ES.1 also shows the ultimate domestic demand for iron and steel materials, namely iron and steel contained in goods, and the contribution of iron and steel scrap recycling to crude steel production.

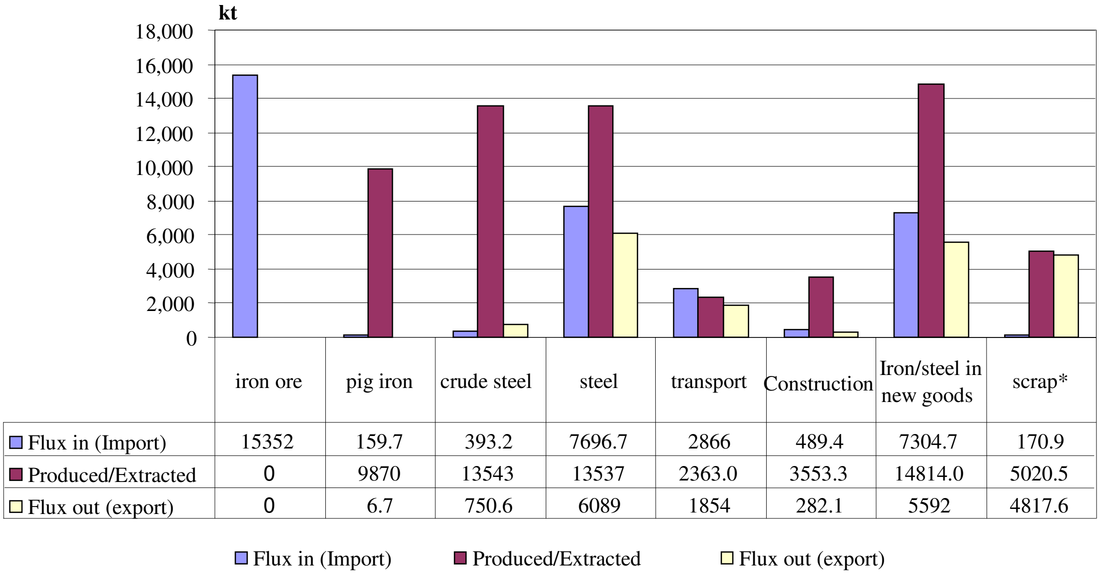
The ultimate domestic demand slightly declined from around 13 million tonnes in 1968 to 12 million tonnes in 2001 with an annual decrease rate of 0.09%. Output from the electric arc furnace (EAF) route that uses ferrous scrap as a raw material to produce crude steel decreased with an annual rate of 0.79%, from 4 million tonnes in 1968 to 3 million tonnes in 2001. However, the contribution of EAF to total crude steel output in the country was 22% in 1968 and 25% in 2001, varying between 20 and 40% over the period 1968 to 2001.



* series scaled to the right hand axis

Figure ES.1 Iron and steel production and GDP growth

Figure ES.2 illustrates current material flows (i.e. production, imports and exports) in the iron and steel supply chain of the UK. In the upstream production of crude steel, domestic demand is supplied primarily by domestic production. Further downstream in the supply chain, imports and exports are much more significant. Figure ES.2 shows these features for the two main iron and steel application sectors; transport and construction. In the transport sector, imports are larger than production or exports flows. By contrast, in the construction sector, domestic production dominates and essentially balances domestic demand. Overall, domestic production of iron and steel contained in goods is higher than both imports and exports. There is little scrap import but much larger exports of scrap, meaning that the UK recovered more iron and steel scrap than that used in EAF production.



	iron ore	pig iron	crude steel	steel	transport	Construction	Iron/steel in new goods	scrap*
Flux in (Import)	15352	159.7	393.2	7696.7	2866	489.4	7304.7	170.9
Produced/Extracted	0	9870	13543	13537	2363.0	3553.3	14814.0	5020.5
Flux out (export)	0	6.7	750.6	6089	1854	282.1	5592	4817.6

*produced/extracted for scrap refers to consumption of scrap (home, prompt and EOL scrap) at steel producers.

Figure ES.2 Iron and steel material flows in the UK, 2001

Aluminium

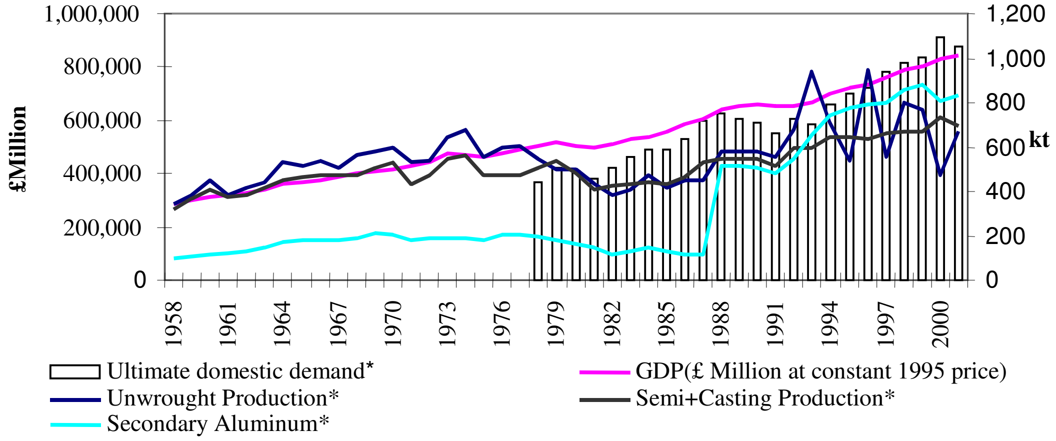
The aluminium time series MFA found that the ultimate demand for aluminium has grown fairly steadily over the past 40 years. In terms of sources of the flows, currently around 60-80% of the goods containing aluminium in use in the UK also come from imports. The significance of imported goods in meeting domestic needs does not mean low domestic production. Around half of the upstream production (i.e. aluminium products and in producing goods containing the metal) in the supply chain is exported.

Unlike the developments over time in the iron and steel supply chain, the upstream aluminium supply chain has seen an increase in production as well as in imports and exports over the past two decades. The aluminium supply chain depends on imported aluminium products to fulfil 40-50% of demands in downstream goods manufacturing. On the other hand, 60-70% of goods containing aluminium produced in the UK are exported.

Accompanying these dynamic material flows are stocks of different material categories including both manufacturing and industrial stocks and stocks of products in use, together with prompt and end-of-life (EOL) scrap arisings. The study indicates that currently about 700,000 tonnes per year of prompt and EOL aluminium scrap are released from use. Like iron and steel, about 70-80% of this scrap is recovered, either reused/recycled domestically or exported. Less than 30% is lost from the economy, of which 80% ends up in landfill.

Over the past 40 years, the country has seen a growing output from the aluminium recycling industry. Secondary unwrought aluminium production has remained fairly stable, currently accounting for 40-50% of total unwrought aluminium output in the UK, whilst the wrought aluminium production predominantly using prompt scrap showed remarkable growth. Despite increasing aluminium recycling, the country currently exports around 40% of recovered aluminium scrap.

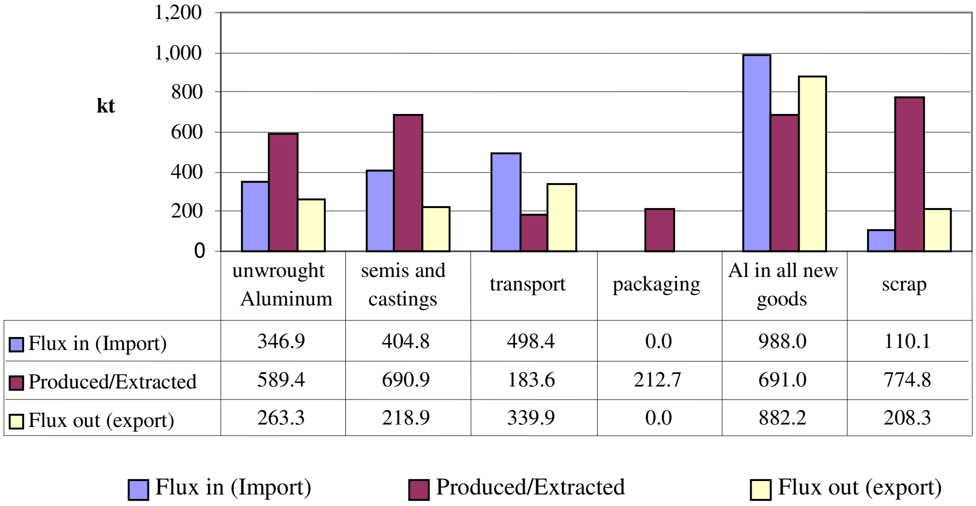
Figure ES.3 shows UK GDP growth and the increase in both unwrought and semi-fabrications/casting aluminium production over the period from 1958 to 2001. Unwrought and semi/casting production increased on average by 1.57% and 1.78% annually while GDP grew on average by 2.5% between 1958 and 2001. Figure ES.3 also shows the time series for ultimate domestic demand of aluminium, i.e. aluminium contained in goods, and secondary aluminium production. The UK experienced an increase in demand for aluminium in goods over the last 24 years, from 400 kt in 1978 to 1 million tonnes in 2001, corresponding to an annual average growth of 3.69%. The consumption of recycled aluminium also increased at an annual average rate of 4.92% in upstream aluminium production. This increase has largely been due to expansion of new scrap recycling (i.e wrought aluminium production predominantly using new scrap) by aluminium remelters.



* series scaled to the right hand axis. Secondary aluminium production refers to aluminium scrap (home, prompt and EOL scrap) consumption in both secondary unwrought production and wrought products production predominantly using aluminium new scrap.

Figure ES.3 Aluminium production and GDP growth.

Figure ES.4 illustrates current material flows in the aluminium supply chain in the UK. There has been more active trade across the whole of the aluminium supply chain than is the case for iron and steel. As an illustration, the figure shows the material flows of the two main aluminium application sectors: transport and packaging. In the transport sector, imports and exports are both very much larger than production of goods for domestic use. Due to the characteristics of the packaging sector (e.g short service life of packaging goods), no net trade was assumed in this sector. Overall, UK demand is predominantly met by aluminium in imported finished goods. The figure also shows high aluminium scrap consumption in both unwrought and wrought aluminium production.



	unwrought Aluminum	semis and castings	transport	packaging	Al in all new goods	scrap
🟦 Flux in (Import)	346.9	404.8	498.4	0.0	988.0	110.1
🟪 Produced/Extracted	589.4	690.9	183.6	212.7	691.0	774.8
🟨 Flux out (export)	263.3	218.9	339.9	0.0	882.2	208.3

Note: as alumina production for the aluminium industry in the UK ceased in 2001, bauxite and alumina material flows are not shown in the chart. For scrap, produced/extracted refers to scrap consumption in aluminium production both in unwrought and wrought products.

Figure ES.4 Current aluminium material flows in the UK: 2001

5. VCA Methodology

Value chain analysis, as applied in this project, starts with the explicit recognition that the stocks and flows of iron/steel and aluminium have associated economic values. As materials are transformed and passed along a chain of production, fabrication, use/consumption and reuse or disposal, the value of the materials is either enhanced or reduced. Note that 'value' in this project refers only to actual monetary values of materials, and does not attempt to put a value on positive or negative environmental (or other) externalities.

Resource productivity and efficiency

By combining material and economic time series data for the steel and aluminium industries, the project has examined resource productivity and efficiency trends in the steel and aluminium industries. Specifically, it has attempted to answer the following questions:

- Are the steel and aluminium industries improving their material efficiency, that is, are they creating more useful output with fewer material inputs;

- Are the steel and aluminium industries improving their energy efficiency, that is, are they creating more useful output with less use of energy;

- Are the steel and aluminium industries improving their material productivity, that is, are they creating more value with fewer material inputs;

- Are the steel and aluminium industries improving their energy productivity, that is, are they creating more value with fewer energy inputs; and

- Is any observed decoupling relative or absolute?

Value chain mapping

As a first step in mapping the value chain, a diagrammatic overview of the steel and aluminium industries is created, with respect to flows of principal materials through the productive chain and their values; flows of inputs and their values; and flows of outputs and their values. Then, values are established for the principal material categories from a range of data sources.

The project has not collected data on the inputs or residual outputs of steel and aluminium production. Rather, publicly available information on outputs was combined with material and value data to investigate some of the value and environmental implications of material flows.

Packaging waste

The UK system of implementation of the EU Directive on Packaging and Packaging Waste (EC/94/62) is also examined. The costs, mechanisms and targets are analysed in relation to steel and aluminium packaging waste.

6. VCA Findings

Resource productivity and efficiency

Iron and steel: Over the time period studied, the UK iron and steel industry has improved the efficiency with which it uses material and energy inputs substantially. In relative terms, fewer inputs are needed per unit of output now compared to 30 years ago. Between 1968 and 2001, the amount of crude steel produced from a tonne of material inputs increased by 6% to 830 kg, and energy efficiency almost doubled, with one TJ of energy producing 53 tonnes of steel in 2001 compared to 27 tonnes per TJ energy in 1968. These improvements are related to the gradual closure of old plants and the uptake of continuous casting techniques.

In absolute terms, there are now fewer material and energy inputs required in total by the UK iron and steel industry compared to 30 years ago. This absolute decline in steel industry resource use is due to the contraction of the industry, the material output of which has declined by 29% in the time period studied, to 13.4 Mt of steel products in 2001. Inputs for crude steel production have decreased by 50% in this time period, to just over 16 Mt in 2001. Energy consumption for the iron and steel industry has decreased by 63.5%, to 260,000 TJ energy consumed in 2001. From an environmental perspective, these are positive findings, as environmental impacts depend on absolute levels of resource use.

Economic labour productivity, measuring value added per worker, has fluctuated quite widely, with rapid productivity declines since 1995, although overall the trend seems to be moving upward. Value added per worker (in crude steel production) was just over £16,000 in 2001. However, material labour productivity shows constant improvements over the whole time period studied. Between 1979 and 2001, material output per worker increased by 75%, to 467 tonnes of crude steel output per worker in 2001. It is therefore clear that while steel production has declined in the UK, the associated employment has declined much more rapidly – by 84% between 1979 and 2001, to 29,000 employees in 2001.

In contrast to the resource efficiency indicators, resource productivity indicators (defined as value added per unit of resource use) show productivity declines over the period studied. The steel industry today generates less value per material and energy inputs compared to 30 years ago. Between 1973 and 2001, the value added, in real terms, per tonne of material inputs in crude steel production decreased by 82% to £29, and the value added per TJ of energy consumed in the iron and steel industry decreased by 61% to £3,800. The decline in value is also absolute, with the gross value added by crude steel production decreasing by 89%, to £554 million in 2001.

The reduction in resource productivity in the iron and steel industry directly reflects the reduction in employment (and therefore value added from labour), lower iron and steel prices (the price of steel in real terms fell by a factor of 4 between 1974 and 2001) and increased material labour productivity in the industry. These factors suggest that resource productivity defined in this way may not be a particularly meaningful indicator at the sectoral level. This is in contrast to the national level, where overall employment remains broadly unchanged by sectoral shifts, and where the indicator would seem to give useful insights into the productivity of natural resource use.

Aluminium: Due to a lack of adequate data, clear resource efficiency trends are hard to establish and results should be treated with caution. No data exist on material inputs into aluminium production, other than the basic formula describing the conversion of bauxite into primary aluminium. Given that the conversion of bauxite to alumina is fixed by stoichiometry, primary material efficiency gains must be negligible.

Primary aluminium production is substantially more energy intensive than secondary production. Both kinds of production have improved their energy efficiency, with primary aluminium production increasing its relative output from 16.6 to 18.2 tonnes per TJ energy consumed between 1980 and 2001, and secondary production from 115 to 128 tonnes per TJ between 1988 and 2001.

For aluminium production as a whole (combining primary and secondary aluminium production), there have therefore been overall efficiency gains. Energy efficiency increased by 47% between 1988 and 2001, to produce 46 tonnes of aluminium per TJ energy consumed in 2001. However, the efficiency gains have been offset by the growth in total output, so that total energy use has increased. As aluminium output grew by 45% to almost 1.2 Mt, total energy consumption was up 15% to 25,000 TJ in 2001.

This analysis demonstrates the sensitivity of the industry, in terms of levels of energy efficiency and absolute energy use, to the relative proportions of primary and secondary aluminium production. According to the data analysed, primary smelting uses about seven times as much energy as refining and remelting activities. The significant improvements in energy efficiency are positive, as is the growth in the industry; however, the total increase in energy consumption is less desirable from an environmental point of view.

Economic labour productivity, value added per worker, has fluctuated quite widely, in what appears to be a gradual upward trend. Value added per worker was about £35,000 in 2001. However, material labour productivity shows constant and dramatic improvements over the whole time period studied. Between 1980 and 2001, material output per worker almost tripled, to 58 tonnes of aluminium products per worker in 2001. Even though UK production of aluminium semis and castings more than doubled between 1980 and 2001, the associated employment declined by 56% in the same time period, to 12,000 employees in 2001.

In contrast to the energy efficiency indicators, resource productivity indicators show productivity declines over the period studied. It was not possible to create a material productivity indicator of the form ‘value added per unit of material input’ for the aluminium industry, as no data on materials consumed were available. Data on outputs of semis and castings were therefore used to formulate a proxy material productivity indicator. This indicator showed wide fluctuations in what appeared to be a downward trend: the value added, in real terms, per tonne of aluminium output decreased by 56% to £600 in 2001. Despite growth in output, value added by the industry also declined in absolute terms: the value added by the UK aluminium industry decreased by 46%, to £416 million, between 1980 and 2001.

It was also not possible to create an energy productivity indicator for the aluminium industry, as the data on value added and the data on energy consumption referred to different parts of the industry. A proxy energy productivity indicator was constructed for purposes of broad trend illustration. This indicator shows a steady decline in value added per unit of energy consumed since 1995.

As with the iron and steel industry, the reduction in resource productivity in the aluminium industry directly reflects the reduction in employment (and therefore value added from labour), lower aluminium prices (which almost halved in real terms between 1974 and 2001) and increased material labour productivity in the industry. For both steel and aluminium, therefore, resource efficiency indicators demonstrate significant improvements over the time period studied, whereas resource productivity indicators, employing monetary output variables, demonstrate declines. This provides further support for the conclusion above that resource productivity may not be a particularly meaningful indicator at the sectoral level. Again, this is in contrast to the national level (where overall employment remains broadly unchanged by sectoral shifts), where the indicator would seem to give useful insights into the productivity of natural resource use.

Value chain mapping

Iron and steel: Combining data on the values of different iron and steel material categories (see Figure ES.5) with data on their flows through the UK economy enabled a mapping of the UK iron and steel value chain to be drawn. A summary of the results is provided in Table ES.1.

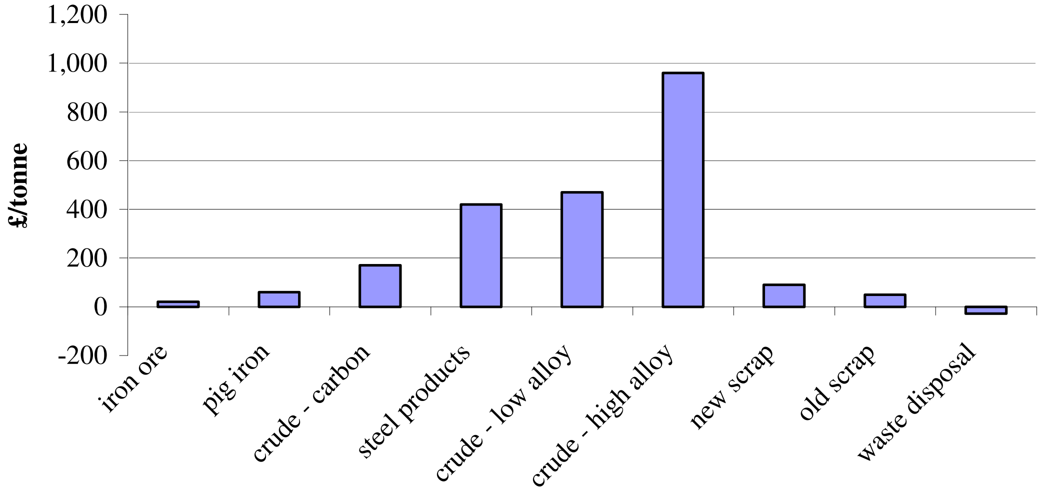


Figure ES.5 Iron and steel principal category values

From the table, it is clear that the major value adding activities are crude steel production, particularly through the electric arc furnace (EAF) route, and the production of steel products. However, there are very large quantities of EOL steel scrap (see above), the value of which is estimated at £500 million. The cost of the steel revealed by the MFA to be landfilled as waste is estimated at £56 million. On the other hand, if this material could be recovered and sold at the price of old scrap (£50/tonne), it would have a value of £100 million.

Table ES.1 Iron and steel summary table, 2001[2]

		Domestic production		Imports		Exports		Net Imports = Imports - Exports	
Material category		Weight (kt)	Value (million)	Weight (kt)	Value (million)	Weight (kt)	Value (million)	Weight (kt)	Value (million)
Iron ore				15,112	£302.2			15,112	£302.2
Pig iron		9,870	£592.2	160	£28.8	7	£3.6	153	£25.2
Crude steel	BOF	10,271	£1,746.1	393	£121.8	751	£217.8	-358	-£96.0
	EAF	3,272	£1,110.8						
Steel products		14,814	£6,221.9	7,697	£2,924.8	6,089	£2,557.4	1,608	£367.4
Scrap	new	1,383	£124.5	171	£478.8	4,818	£385.4	-4,647	£93.4
	old	10,013	£500.7						
Scrap to landfill		2,000	-£56.0						

The final column displays net imports (imports – exports) in both weight and value terms for the different iron and steel material categories. As revealed by the MFA, there was a substantial net import of steel products, and a net export of crude steel and

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[2] It was not possible to add CO_2 emissions to this table, as data on greenhouse gas emissions from all the various processes were unavailable and/or insufficiently transparent.

scrap. However, in value terms, there was a trade surplus only for crude steel, due to the very high value of scrap imports.

Aluminium: Combining data on the values of different aluminium material categories (see Figure ES.6) with data on their flows through the UK economy enabled a mapping of the UK aluminium value chain to be drawn. A summary of the results is provided in Table ES.2.

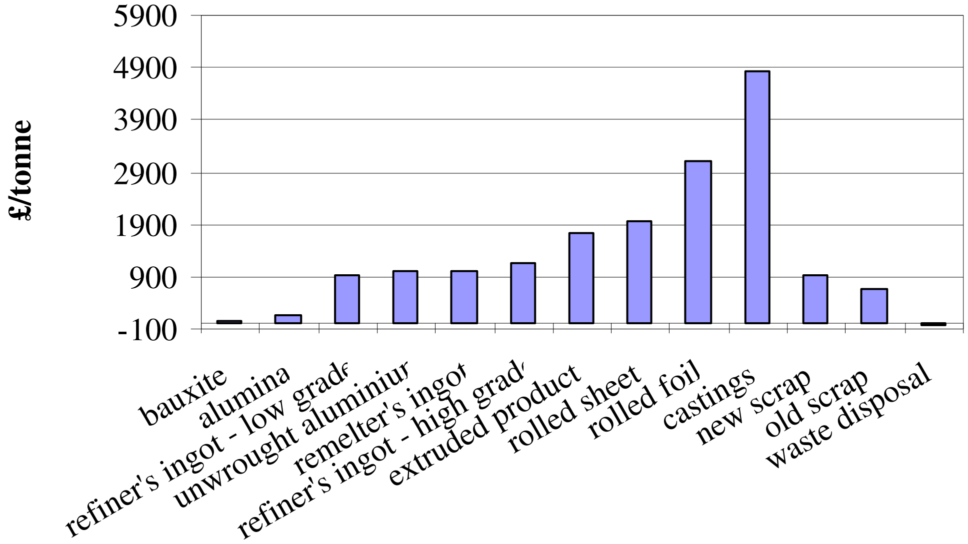

Figure ES.6 Aluminium principal category values[3]

Table ES.2 Aluminium summary table, 2001

Material category		Domestic production			Imports			Exports			Net Imports = Imports - Exports		
		Weight (kt)	Value (million)	CO_2 (kt)	Weight (kt)	Value (million)	CO_2 (kt)	Weight (kt)	Value (million)	CO_2 (kt)	Weight (kt)	Value (million)	CO_2 (kt)
Bauxite*					163	£8.2							
Alumina					704	£126.7	943				704	£127	943
Aluminium	primary	341	£344.2	3,385	347	£381.6	1,113	263	£292.3	845	84	£89	268
	refiners' ingot	249	£251.6	199									
	remelters' ingot	585	£591.2	185									
Semi-fabricated products	rolled products	385	£935.0	298	405	£777.2	308	219	£385.3	167	186	£392	142
	extruded products	177	£309.9	160									
	castings	129	£621.8	68									
Scrap	new	81	£74.3	83	110	£73.8	12	208	£145.8	23	-98	-£72	-11
	old	672	£436.7										
Scrap to landfill		160	-£4.5	na									

Note: Data on CO_2 equivalent emissions for alumina from SimaPro, for scrap (referring to the transport emissions generated in their collection) from Davis (2004), all other EAA (2000). For imports of aluminium and semifabricated products, the same proportions that exist in the UK in terms of production of sub-categories have been assumed.

*Bauxite imports are not for aluminium production, displayed only for illustration purposes.

The major value adding activities are aluminium production and the production of semifabricated aluminium products and castings. However, aluminium scrap is also a highly valuable material, and the total value of old and new scrap is estimated at over

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[3] Note that the value of castings is likely to be exaggerated; however, it is used in the absence of other data (see Section 7.2).

£500 million. In spite of this, the MFA showed that substantial quantities of aluminium are disposed of as waste, at an estimated cost of £4.5 million. On the other hand, if this material could be recovered and sold at the price of old scrap (£650/tonne), it would be worth £104 million.

In addition to weight and value data, the table includes estimates of CO_2 emissions associated with the various material categories. These estimates should be treated with caution, but can nonetheless give an idea of the order of magnitude of greenhouse gas emissions associated with the different stages in the aluminium production and use chain.

The final column displays net imports (imports – exports) for the different aluminium material categories. In terms of weight, value and greenhouse gas emissions, exports exceed imports only for aluminium scrap. Greenhouse gas emissions associated with UK aluminium production and use are largely associated with domestic production, with net imports contributing to around one third (1,342 kt) of the CO_2 emissions from domestic manufacture (4,378 kt).

Packaging waste

It seems likely that the UK system of implementing the Packaging Regulations through the tradable mechanism called Packaging Recovery Notes (PRNs) has generally contributed to an increase in the recycling of packaging waste which is cost effective, if modest compared to some other European countries. The PRNs are bought by the companies that have recycling and recovery obligations from accredited reprocessors or accredited incinerators of packaging waste, and used as evidence that the companies have complied with their recycling/recovery obligations.

The lack of a viable mechanism for sanctioning failing compliance schemes has led to lower levels of demand for PRNs, reducing the marginal costs of packaging recycling and recovery in the UK, and hence, the prices paid for PRNs. The fluctuations in the PRN price have not helped planning for the development of either the collection or reprocessing infrastructure. PRN prices seem strongly driven by recycling targets. It seems that unless targets continually increase, PRN prices fall back, which hinders the smooth development of the collection and reprocessing infrastructure. A positive conclusion from the price sensitivity of PRNs to targets is that, in the industrial and commercial sector at least, it seems that once collection and reprocessing infrastructure is in place, reduced levels of subsidy are required to keep it operational.

The volume of steel and aluminium packaging in household waste, the increasing targets for recovering packaging waste in the future, and pressures to recover other waste streams from households, make it both desirable and necessary for household waste to play a larger part in meeting the packaging waste recovery targets in the future than it has in the past. This means that local authorities are going to need greater levels of recycling finance. To be consistent with the producer responsibility principle, this finance should be provided by the packaging industry (and therefore the cost passed on in the cost of the packaging) rather than the taxpayer. The PRN scheme should be amended to ensure that this is achieved.

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1 INTRODUCTION

1.1 Background

Economic activity is accompanied by resource flows related to the extraction, production, consumption and use, and disposal of materials and products. These flows have environmental impacts, ranging from 'source' problems such as depletion or overexploitation of resources, to 'sink' problems, which refer to the environment's limited capacity to absorb emissions. Problems of pollution and waste occur when such limits are exceeded. Many current environmental problems are rooted in the scale and scope of society's material throughput, suggesting that a *decoupling* of economic growth and resource flows is needed to reduce environmental impacts while improving quality of life.

Such a decoupling hinges on improvements in resource productivity, defined broadly as doing more, or getting more value, with fewer inputs and less resulting pollution. The scale of the economy and the pressing nature of many environmental problems mean that resource productivity improvements must now be radically increased.

Information on the quantities of flows relating to specific materials, to economic sectors, or through geographic areas is therefore vital for the sustainable management of resource flows, particularly at the end-of-life stage where resources become wastes. In light of rising waste disposal costs and other increasingly stringent environmental legislation, the management of resource flows is gaining importance both at the level of individual companies and industries, and as a policy issue.

The Biffaward Mass Balance Projects

As part of the UK Government's efforts to tackle the growing problem of waste, a tax on landfill was introduced in 1996. Under the regulations, landfill site operators are able to claim tax credits in return for financial contributions to environmental projects that fulfil certain objectives. In 1997, Biffa Waste Services set up the Biffaward scheme, which is administered by the Royal Society of Nature Conservation, to support projects which contribute to a range of environmental improvements. To date, this respected landfill tax credit scheme has distributed close to £60 million to 700 different projects. These projects include a series of Mass Balance projects under the Biffaward Programme on Sustainable Resource Use.

The *Mass Balance* suite of Biffaward projects, coordinated by the Sustainable Economy Programme of Forum for the Future, has generated data on resource flows through the UK economy, in a common framework to maximise the usefulness of the data (Linstead and Ekins, 2001). The projects rely on the mass balance principle, grounded in thermodynamic laws, that the total mass of inputs must equal the total mass of outputs, in some form. This principle of balance helps uncover hidden flows in the economy, such as in the form of emissions to air, or stocks of materials, for example stocks of a material contained in a landfill.

A comparison is drawn between the data generated and categorised in this way and the system of national economic accounts, as it is hoped that the system of resource accounts resulting from the Mass Balance projects will aid resource management in the same way that the economic accounts are instrumental to the economic management of the country.

1.2 Aim of project

This report is the joint report of two separate projects funded under the Biffaward Mass Balance scheme: the *Material Flows of Iron/Steel and Aluminium in the UK*, undertaken at the University of Surrey's Centre for Environmental Strategy; and the *Economic Dimensions of Material Flows of Iron/Steel and Aluminium in the UK*, undertaken at the Policy Studies Institute. In practice, the two projects functioned in many respects as one project with two distinct parts, and there was a high level of mutually beneficial collaboration between the project partners. Throughout the report, the former project is referred to as the material flow analysis (MFA), and the latter project as the value chain analysis (VCA).

Steel and aluminium are two of the commonest structural metals in the UK, and are produced and exist in society in great quantities. The concept of sustainable development presents particular challenges for primary industries such as these, because environmental sustainability requires the conservation and prudent use of non-renewable resources and the management of environmentally damaging impacts associated with the extraction and processing of these resources. However, to the industries' advantage, well-established techniques and infrastructure exist to recycle these valuable metals, with significant savings in energy and material inputs and a reduction in environmental impacts as a result of such efforts.

The purpose of the material flow analysis has been to provide a reliable set of data on the flows and stocks of these metals as they pass through the UK economy. Knowledge of these stocks and flows is vital to aid decisions concerning recovery and recycling, but has nonetheless remained inadequate for informed policy decisions. The project has narrowed this data gap. In addition, the MFA has developed a time series approach to modelling the stocks in use, as steel and aluminium exist in a range of goods with different lengths of service lives, such as packaging materials, vehicles, or buildings – some of which can remain in use for several decades.

The MFA has therefore collected and synthesised yearly data, going back for steel to the 1960s and for aluminium to the 1950s, on the material flows associated with the production, use, recovery and reuse of steel and aluminium in the UK. This includes data on primary and secondary raw materials; finished materials such as iron and steel products and semi-finished aluminium products; metal content in final goods containing steel and aluminium; and imports and exports of these materials.

To enhance the policy relevance of the MFA, a parallel value chain analysis was carried out, which started to relate the material flows to economic variables, as this consideration of economic dimensions sheds further light on such concepts as resource productivity and sustainable resource management. The purpose of the VCA was to provide a methodology for investigating the economic values associated with the current material flows and stocks of steel and aluminium in the UK; to map the value chain corresponding to the material flows; and to examine how these values relate to resource productivity and recovery.

1.3 Material Flow Analysis

The core of industrial ecology as an emerging scientific field is the study of the industrial metabolism. Understanding the structure, quantity and quality of the industrial metabolism requires analysis of material flows from resource extraction to final waste disposal. This entails determining and quantifying the types of material flows and cycles, e.g. the amount of physical input into an economy, material accumulation in the economy, and outputs to other economies or to nature. There have been several developments in statistics such as national environmental accounts to match this requirement. Material flow analysis (MFA) is another development, which examines how materials and energy flow into, through, and out of a system.

The principle behind MFA is the first law of thermodynamics on the conservation of matter: that matter, i.e. mass or energy, is neither created nor destroyed by any physical transformation (production or consumption) processes. This material balance principle provides a logical basis for physical bookkeeping of the economy-environment relationship and for the consistent and comprehensive recording of inputs, outputs and material accumulation.

There are different types of MFA models[4], in which the target of the analysis can be a selected substance (e.g. a chemically defined element or compound such as carbon dioxide), a material (e.g. natural or technically transformed matter that is used for commercial or non-commercial purposes such as iron and steel), a product (such as a fuel cell), or an economy. In life cycle assessment (LCA), the MFA methodology targets one product in a specific or average life cycle. MFA when used at a national level provides an aggregate overview, in mass, of annual material inputs and outputs of an economy, including inputs from and output to the national environment and the physical amounts of imports and exports. The net stock change or net accumulation is equal to the difference between inputs and outputs.

MFA methods are gaining in popularity as a means to apply a systems view to many types of decisions: from product development and design, to business management, and to public policy. Generally two basic types of MFA can be distinguished (Bringezu, 2003). The first type starts with specific problems related to selected substances or

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[4] See Bringezu, *et al.* (1995), Cooper (2000), Bouman, et al. (2000), and Kandelaars (1999).

materials and aims for detoxification of these material flows and reduction of pollution. Examples of this type of MFA include studies on heavy metals, nitrogen, carbon and chlorinated substances. The second type starts with the question whether the volume and structure of the throughput of selected sectors or regions are sustainable. This type of MFA aims for dematerialisation and the restructuring of the industrial or societal metabolism and increase of resource productivity. Examples of this second type MFA include studies on the construction and chemical sectors. Other examples are studies of cities, regions or national economies that analyse selected material flows or the total material throughput.

The first type of MFA is normally applied to control the flow of hazardous substances such as heavy metals. Findings from this type of MFA have a significant influence on governmental policy as well as industries themselves. The second type of MFA is useful in providing material flow accounts for regular use in official statistics, deriving indicators for progress towards sustainability and supporting policy debate on goals and targets. These environmental pressure indicators include total material requirement (TMR) and direct material input (DMI). These material flow indicators are appearing more frequently in official outputs of many institutions and organisations such as Eurostat, the European Environment Agency and the United Nations.

However, some MFA-related issues have not yet been addressed. ConAccount, an EU-funded concerted action for the co-ordination of regional and national material flow accounting for environmental sustainability, was established in 1996 in order to support information exchange and further research.[5] Activities related to products and life cycle analysis are currently led by ISO standardisation efforts.

The purpose of this MFA is to provide a reliable data set on the flows and stocks of iron, steel and aluminium within the UK boundaries. Unlike other MFA studies that use a simple “current account” approach to mass balance and therefore only account for one or two years’ flows, this MFA features a time series approach. This time series feature will therefore help understand how the significant stocks of these metals in use have built up historically. Data are assembled on a yearly basis, reaching back several decades in accordance with the Mass Balance Framework (Linstead and Ekins, 2001).

To the extent possible, the time series data are disaggregated into different broad categories of applications (e.g. construction, transport and packaging). By matching the time series to the predictions of a dynamic MFA model, it is expected to obtain estimates for the quantities of these metals including those contained in products such as vehicles, machinery, food cans, etc., in current use. Furthermore, by applying life-span distributions to each broad category of goods that enters use in the UK, the model infers estimates of available end-of-life (EOL) waste of these metals, and hence the level of closure of the supply loop of these in the UK.

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[5] See http://www.conaccount.net for more detail.

1.4 Value Chain Analysis

In its most common application, value chain analysis is a strategic management or cost accounting tool used to diagnose and enhance a company's competitive advantage. The analysis does this through a breakdown of an organisation's strategic activities (so called value activities); an examination of their costs; and the streamlining and coordination of the linkages of those activities within the 'value chain'. This exercise can enhance the efficiency of a company's internal operations and aid decisions concerning investments and expansions (Porter, 1985).

Competitive advantage stems not only from the value activities in themselves, but also from the way they are related to each other through linkages within the value chain. Undertaking value chain analysis at the industry level – examining linkages at the level of an industry or a whole supply chain – helps companies make strategic decisions, such as if and how to expand current activities, where to focus capital investments, and helps to identify suitable suppliers and buyers.

Value chain analysis, as applied in this project, starts with the explicit recognition that the stocks and flows of iron/steel and aluminium have associated economic values. As materials are transformed and passed along a chain of production, fabrication, use/consumption and reuse or disposal, the value of the materials is either enhanced or reduced. Note that 'value' in this project refers only to actual money values of materials, and does not attempt to put a value on positive or negative environmental (or other) externalities.

The value of iron ore or bauxite represents the value added in the process of mining it from the earth. The value of pig iron and primary steel, or aluminium oxide and primary aluminium, contain, in addition, the value added by the various smelting and casting processes, whereas the values of intermediate and final goods include the value added by any further additional material, energy and labour inputs. When the final products are put to use, their value starts to decline as they are either consumed or depreciated. These products will eventually reach the end of their service lives, at which point their value can be negative, if they have become 'wastes' and need to be disposed of, or remain positive if the products or parts of them can, with additional processing, be reused for the same purpose or recycled into some other product.

The value of products at their end-of-life stage therefore depends to a great extent on the shape and form of waste management regulations, such as waste reduction targets and the landfill tax, and other environmental regulations, such as producer responsibility regulations, which can impact on the design of products which in turn will affect their ease of disassembly and reuse; and on the existence of well-developed markets for re-used and recycled products.

If such markets exist, and the materials embedded in the end-of-life products have high value uses, then the value of materials for reuse and recycling is likely to be quite high and reuse/recycling is likely to take place. On the other hand, if the recycled uses are of low value, need considerable reprocessing and their markets are less well developed, then the value of the end-of-life materials is likely to be low or even negative, and their reuse or recycling is unlikely to occur in the absence of waste reduction targets, high landfill disposal costs, or other regulatory drivers.

The two concepts of a chain of activities/actors in production and of economic competitiveness strike fundamental chords with certain aspects of environmental management, and there is a clear link between economic competitiveness and environmental performance through resource productivity improvements. Reducing pollution and maximising profit share basic principles of enhancing productivity and minimising inputs, waste and wasteful behaviour. Both the literature around economic competitiveness and inter-organisational environmental management stress the need to identify hidden or unanticipated costs; the need for information and cooperation between and governance of different actors in the chain; and the potential to realise system-wide efficiencies benefiting parties throughout the production or value chain.

The value chain analysis in this report adds to the limited extant body of work linking material flows with economic considerations, in the hope of contributing to the emergence of a coherent framework for these sorts of assessments rather than the current piecemeal and case-by-case approach. The work undertaken suggests that the pairing of material flow analysis with a value chain analysis can provide an avenue for successful linkage of the physical and economic dimensions of material flows. Both material flow and value chain analysis can handle large systems; both have an explicit focus on the different stages of a production chain; and both therefore have an explicit focus on the transformations through the chain, in material or financial terms.

1.5 Wider policy context

Sustainable resource use, which concerns both ensuring adequate supplies of renewable and non-renewable resources and managing the environmental impacts associated with their processing and use, is firmly established in UK environmental policy, although practice is lagging behind principle in this area. As mentioned above, the stage where resources become waste is of great interest for any sustainable resource initiative.

The issue of waste management is particularly relevant for the UK, which has traditionally relied on cheap landfill as a means of waste disposal. England and Wales produce around 400 Mt (Mt) of waste every year, most of which is landfilled. Over 100 Mt of this waste comes from households, industry and commerce, with the balance made up of construction and demolition, agricultural and mining wastes. An estimated 83% of household waste and 54% of industrial and commercial waste is sent to landfill, making recovery rates very low compared with many other parts of Europe (DETR, 2000).

Landfilling is becoming increasingly problematic: not only does it represent a loss of potentially valuable resources, but it is also polluting and gives rise to emissions of methane, a greenhouse gas; is unpopular with those who have to live near landfill sites; and certain parts of the country, such as the South East, are running out of space in their available landfill sites. Ideally, environmental improvements should be pursued within a ‘waste hierarchy’ of different approaches (Figure 1.1). To reduce the environmental impact associated with a material or product, the first choice should be to avoid or reduce its use. If this is not possible, reusing it in its same form should be attempted. Recycling and incineration are less desirable options than the aforementioned, but are considered preferable to landfilling.

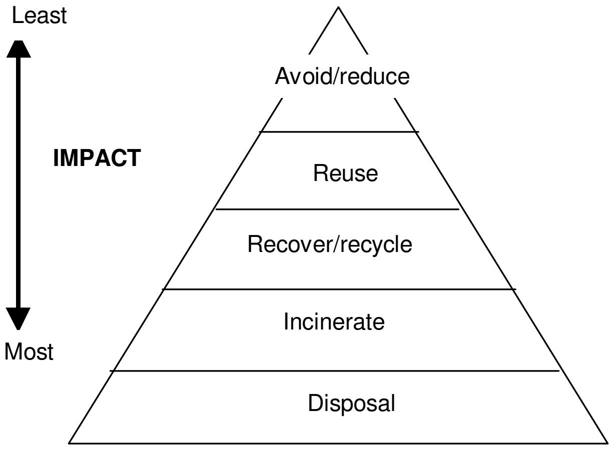


Figure 1.1 The waste hierarchy (Hines et al., 2000)

National policy is largely driven by European initiatives and shaped through the implementation of specific EU Directives and the interpretation of more general strategies. The current EU Sixth Environmental Action Programme (European Commission, 2001a) identifies sustainable use of resources and management of waste as one of four priority areas for action. As part of this programme, three interrelated thematic strategies, on sustainable resource use, waste prevention and recycling, and integrated product policy, are being prepared. These will further understanding and identify where action needs to be taken, and will contribute to more coherent policies for decoupling resource use and environmental impacts from economic growth.

In addition, sustainable resource management in general and resource productivity improvements in particular are fundamental to delivering sustainable development as defined by the UK government (DETR, 1999), as high and stable levels of economic growth need to be achieved with a prudent use of natural resources and effective protection of the environment.

Key legislative documents are the EU 1975 Waste Framework Directive, the 1994 Packaging Waste Directive, and the 1999 Landfill Directive. The requirements and principles laid out in the Waste Framework Directive are implemented in the UK through the 1990 Environmental Protection Act as well as the 2000 Waste Strategy for England and Wales. The Landfill Directive, which introduced changes to the separation and treatment of waste, was transposed into UK law through the 1999 Pollution Prevention and Control Act. The Packaging Waste Directive came about through the EU Priority Waste Streams Programme, which focused on specific materials – priority waste streams – and which has also seen legislation on tyres, end-of-life vehicles, waste electrical and electronic equipment, construction and demolition waste, and healthcare waste (Gervais, 2002a, b). Section 8 will deal specifically with the packaging waste regulations, which set overall and materials specific recovery and recycling targets for certain types of packaging, including steel and aluminium packaging.

The Waste Strategy for England and Wales (DETR, 2000) is aimed at household and industrial and commercial waste, and sets ambitious targets for the reduction, recovery and recycling of these wastes (see Box 1.1). However, while the strategy proposed certain indicators for use by local authorities in monitoring their performance, it did not establish a clear framework for collection of data.

Box 1.1 Waste Strategy 2000: Targets

Targets for Industrial and Commercial Waste:

- reduce the amount of industrial and commercial waste going to landfill to 85% of that landfilled in 1998 by 2005

Targets for Municipal and Household Waste:

Recovery (obtaining value through recycling, composting, or other forms of material recovery):
- recover value from 40% of municipal waste by 2005; from 45% by 2010; and from 67% by 2015

Recycling and Composting of Household Waste:
- recycle or compost at least 25% of household waste by 2005; 30% by 2010; and 33% by 2015

Source: DETR (2000), *Waste Strategy 2000: England and Wales*. London: TSO.

The government is also committed to environmental tax reform: using fiscal measures to increase incentives to reduce environmental damage by taxing the use of environmental resources rather than labour. Currently, these measures include the Climate Change Levy, the landfill tax, and the aggregates tax. The landfill tax, introduced in 1996, applies a charge per tonne of waste disposed of in landfill. There are two rates of tax: one for inert waste, such as concrete or ash, currently set at £2/tonne; and one for all other active wastes, which is currently set at £14/tonne. The UK rate for active waste is currently escalating at £1/tonne per year, until 2004/05, when it will rise by £3/tonne per year until it reaches a medium-term rate of £35/tonne. However, some other European countries have already considerably higher landfill taxes, such as the Netherlands, which currently has a landfill tax of £45/tonne, and Denmark, with a rate of £34/tonne (Strategy Unit, 2002).

1.6 The Standard Industrial Classification (SIC) system

The mass balance framework stipulates that industrial sectors studied are classified according to the UK Standard Industrial Classification (SIC) codes defined by the Office of National Statistics (ONS).

The UK introduced the SIC system in 1948 for classifying businesses, industries and economic sectors according to their principal economic activity. The system provides a framework for collection and analysis of economic data, which promotes uniformity. However, over time the structure of economic activity changes, as existing industries undergo various transformations and introduce new products, and entirely new industries emerge. Also, the UK system is committed to consistency with the European NACE system issued by Eurostat.

Therefore, the classifications need regular updating, and the UK SIC system was revised in 1958, 1968, 1980, 1992, 1998 and 2003 (ONS, 2002), although the last two revisions were relatively minor. Currently, the UK system divides economic activity into 17 sections, such as manufacturing, transport and communications, or education. The sections are further divided into subsections, then divisions, groups and classes. Manufacturing for example is section D, which has 14 subsections and 23 divisions. Iron and steel and aluminium are both part of manufacturing.

1.7 The UK steel and aluminium industries

The UK metal industries employ around 250,000 people, in 7,000 companies with around £8 billion of sales (DTI, 2003). Steel and aluminium are key structural metals and materials of strategic importance for the UK manufacturing sector. Main markets are construction, transport, engineering, and other manufacturing, such as packaging in the case of aluminium.

Both industries are materials and energy intensive, responsible for significant environmental impacts. Many of the associated environmental impacts however lie outside the UK's borders, as this is where mining of ores and ancillary materials takes place, often with great environmental disruption for example through the generation of large amounts of (increasingly temporary) overburden. In the UK, key environmental concerns for the steel industry are the emissions of air pollutants and the management of solid wastes, and for the aluminium industry the key concern is the generation of greenhouse gases, such as carbon dioxide and the more potent perfluorocarbons, as the industry is highly energy intensive. Both steel and aluminium have high rates of recycling, which saves great amounts of raw materials and energy.

The two industries face very similar pressures and trends, related to the evolving environmental legislation of the EU, and to the changing structure of the UK economy as well as increasing globalisation of trade. The metals industry has experienced a high rate of consolidation in the past decade, which looks set to continue. In 1999, British Steel and Dutch Koninklijke Hoogovens announced a $2.7 billion merger to form the Corus Group, which is the world's third and Europe's largest steel producer. For aluminium, there were two significant mergers in 1999: the merger of Alcoa, the world's largest aluminium producer, and Reynolds Metals, the third largest producer; and that of Alcan, the second largest producer, and Swiss Algroup.

Steel producers have been faced with static demand in most parts of the world, and the consolidations occurred within the context of reducing over-capacity. However, despite being regarded as one of the most productive steel industries in the world (House of Commons, 2003), the UK steel industry has experienced difficulties in recent years. Corus, which is responsible for 90% of UK steel output, had to cut 12,000 jobs and close two steelworks in 2001, in an attempt to stem the decline in profitability. It is hoped that these changes will help the industry to maintain a fair share of the domestic market, which has seen an increased reliance on imports to meet demand. This trend has been compounded by the general decline in the UK manufacturing sector, and in the short-term exacerbated by the relative strength of the sterling. Global aluminium production capacity was cut by 1.5-2 Mt annually in the early 1990s (*New Steel*, 1999), and demand as well as production is now growing steadily in the UK.

Figures 1.2 and 1.3 show the steel and aluminium intensities respectively of the UK economy.

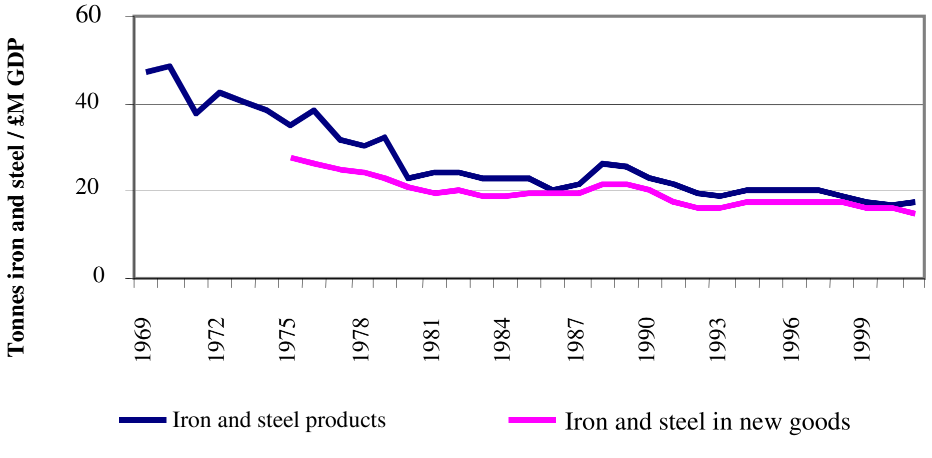


Figure 1.2 Steel intensity of UK economy (tonnes /£million GDP, 1995 values)

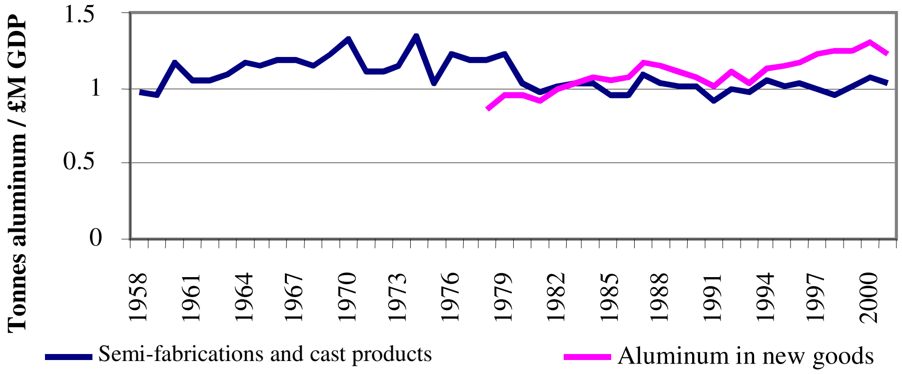


Figure 1.3 Aluminium intensity of UK economy (tonnes /£million GDP, 1995 values)

The figures show that UK iron and steel production has decoupled from economic growth, whereas aluminium production has grown with it. Similarly, UK per capita consumption of these metals has declined in the case of iron and steel, and increased for aluminium. The apparent consumption of crude steel per person in the UK declined from 350 kilograms in the 1970s, to 220 kilograms per person in 2001. Compared with the per capita consumption of crude steel in the EU and globally, the UK per capita consumption is about half the EU average of 410 kg (IISI, 2002).

The apparent consumption of semi-fabricated and cast aluminium per person has tripled in the period studied: from 5 kg in 1958, to 15 kg in 2001. The per capita consumption of aluminium products in Europe, USA and Japan is 22 kg, 35 kg and 30 kg respectively (EAA, 2002).

2 MATERIAL FLOW ANALYSIS METHODOLOGY

2.1 Introduction

As one of the Mass Balance UK projects, this project aims to understand the stocks and flows of iron and steel and aluminium in the UK economy by carrying out a material flow analysis (MFA). The MFA is employed to reveal past and present patterns of production, transformation and consumption of these metals in the UK.

According to Linstead and Ekins (2001), the purpose of tracking the flow of the metals from the point of entry into the economy to their point of final disposal by using mass balance principle is to identify:

- the quantities of the basic metals themselves;
- the quantities of the major components and products into which the metals are incorporated;
- the flow of the metals through the economic sectors which own the metals for consumption or production purpose and which produce positive-, zero- or negative-value materials as waste; and
- the industrial sectors within which the metals are physically located.

The system boundaries of the study are the geographical borders of the UK. Using national borders as system boundaries typically facilitates data collection, as many relevant data sets are usually compiled on a national level. The disadvantage, however, is that highly aggregated data will not show the geographical distribution of the materials in the UK.

In this analysis, "*iron and steel*" refers to all economic iron and steel quantities, including all ferroalloys and other elements contained in the material. Those elements include carbon (C), Sulphur (S), Manganese (Mn) and Chromium (Cr). The content of carbon in iron and steel product range between 0.05-5%, while the content of alloy elements range between 1% to 30%. According to ISSB statistics, delivery of alloy steel from UK producers accounts for around 10% of total delivery of steel products. Likewise, "*aluminium*" means all economic aluminium quantities, including all aluminium alloys and other elements contained in the material. The content of alloy elements in aluminium alloy product varies between 1-10%, mostly around 3-5%.

The models of UK iron, steel and aluminium material flows comprise three main categories of processes. Based on a previous study of material and exergy flows through the UK iron and steel sector (Michaelis and Jackson, 2000a, b), three main categories of processes should be distinguished: *production*, *fabrication and manufacturing*, and *use*. This choice seems to be fairly standard for this kind of analysis (Graedel *et al.*, 2002). Where necessary these processes are further divided into sub-processes, such as production in blast furnaces and basic oxygen furnaces. These process groups describe the transformations from one material category into another, i.e. all material conversions taking place within UK borders.

The material categories for iron and steel are: iron ore; home scrap; iron and steel prompt and end-of-life scrap; pig iron; crude steel; iron and steel industry products; and iron and steel contained in new goods. The material categories for aluminium are: aluminium ore (bauxite); alumina; aluminium prompt and end-of-life scrap; unwrought aluminium; aluminium industry products; and aluminium contained in new goods.

Home scrap is defined as scrap produced at the iron and steel works and aluminium plants respectively; this scrap is recycled internally. Prompt scrap, also called new scrap, is generated in the manufacturing of various goods, whereas end-of-life, or old, scrap is generated when goods become obsolete after use.

The iron and steel and aluminium material categories and the three main processes including their sub-processes will be elaborated in Sections 3 and 4.

2.2 System modelling for the MFA: general flows

The main elements of an MFA are economic processes and material stocks and flows of interest (Bringezu and Moriguchi, 2002). The systems view of the processes and material stocks and their connecting flows is referred to as the *life cycle* in industrial ecology and the *supply chain* in management science. However there exists neither a unified way of assembling these elements into the investigated system nor scientifically binding accounting rules. Figure 2.1 explains the relationship between processes and different mass balance data employed in this study.

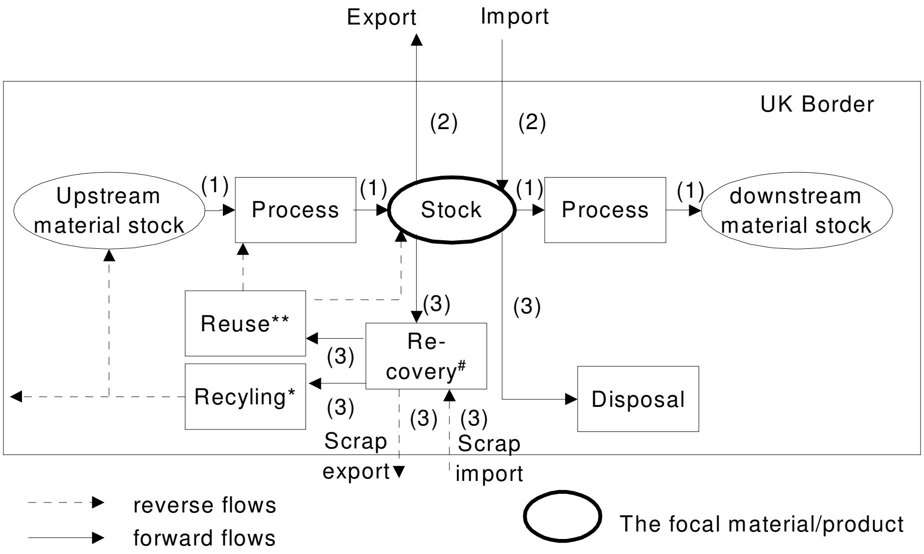
The processes transform a material from one category to another: in other words, they consume upstream stock and add to the stock of output material. The system includes stocks that are stored inside the economy before being transformed into another material or being disposed as well as the import and export activities, i.e. transportation across UK borders.

It is necessary to differentiate between two kinds of stocks: industrial and commercial stocks, and stock in use (Sinclair *et al.*, 2001). Industrial and commercial stocks are those held by manufacturers, distributors and retailers to buffer the difference between supply from their suppliers and demand from their customers. Stocks in use are those that are already in service for their designed purpose, such as steel in a building or aluminium in a car. It is important to note that the total stock of a material category is made up of the stocks of the producers, consumers, traders and stockholders of that category.

In spite of the existence of lead times, transformation and transportation processes are typically modelled in MFAs as being instantaneous, with the important exception of the use phase of final goods. It is, therefore, assumed that all processes, apart from the use stage, process the material input in the same year they are received. For input into use, data have been collected for several decades back, enabling EOL scrap arisings to be modelled taking into account the time delay for goods in use. A detailed treatment of the use phase is given in Sections 3 and 4.

Processes and stocks are linked through the material flows. The mass balance framework (Linstead and Ekins, 2001) gives a well defined data categorisation to deal with these different material data: flux in; flux out; used; extracted/produced; initial stock; final stock; recovered/recycled; final disposed. As the boundaries of this mass balance study are the UK borders, fluxes in and out mean imports and exports.

At the core of any MFA are stocks or reservoirs of materials of interest. These material categories have to be clearly specified and their stocks must have clearly defined boundaries, in this study, the borders of the UK. Figure 2.1 gives a simplified representation of the supply chain of a material/product, where the relationships between two adjacent transformation processes and three material/product stocks are shown. There are three ways to increase or decrease the focal material/product stocks, as shown in



In the figure:

(1) denotes flows involved in transformation processes mentioned in the text above
(2) denotes flows involved in transportation processes
(3) denotes flows involved in recovery, recycling /reuse and disposal

"Recovery" refers to activities where used products or materials are collected/sorted and ready to be reused or recycled. The recovered materials can also be imported to be reused/recycled overseas or imported from abroad.

** "reuse" includes two types of activities. One type refers to a used product returned to be refurbished and ready to be used, so that the refurbished product still belongs to the same category of stock without further processing. Another type refers to a used product, which is disassembled with some of its components or parts taken for refurbishing while others are contaminated or worn so that they must be reprocessed or treated as waste. Components which are reused must be remanufactured by re-assembly with other components into a remanufactured product.

* "Recycled refers" to activities where a product or part of its components cannot be reused and have to be reprocessed back to one of the upstream material stocks.

Figure 2.1 System modelling for the MFA

Figure 2.1. The first is through transformation processes within the boundaries of the UK, which either extract/produce the focal material from upstream materials of different categories or consume/use it by transforming it into downstream materials of different categories. Production processes thus increase the stock, while consumption processes decrease the stock. The second way is through transportation processes across the UK borders, i.e. trade. In these processes the focal material remains in the specified form but enters/leaves the UK, whereas transformation processes extract/produce or consume/use the material within the UK by changing the nature of the material. The output material of a transformation process can still physically reside within the UK but it belongs to a different material category and therefore to a different stock than the input material to the process.

The third way is through disposal and recovery/recycling/reuse processes. Disposal obviously causes irrecoverable decrease of focal material stock. Recovery/recycling/reuse processes also cause reduction of the focal material stock, but after a period of time, the stock can be replaced by recycling and reuse. In recovery processes, used or damaged or failed material/product is collect and sorted. Depending on the technology availability and contamination/damage of the material/product, in the case of reuse, a recovered material/product can be refurbished and reused in its original form. Another type of reuse, where the material/product is in a poorer condition than the former type and only part of the components and parts can be reused, the product has to be disassembled to salvage the reusable components and parts. These components can then be refurbished and reassembled with other components to make a saleable remanufactured product. Otherwise (and more commonly), the recovered material/product must be recycled back into one of its upstream material forms. The two routes of reuse and recycling reflect what is known in the industrial ecology literature as "*cascaded use*" of material (Mellor *et al.*., 2002). In this study, no disposal, recovery, reuse and recycling data are available for most of the material categories, except for scrap as a whole. Therefore, it is assumed that these flows are too minor to make significant impact on the other flows (e.g extracted/produced, import and export); and this assumption applies to all material categories for both iron/steel and aluminium except for EOL scrap.

Combining the input-output consideration with the mass balance principle the change in stock over a certain period of time can be expressed as:

$$\int_{t_1}^{t_2}(Stock)=\int_{t_1}^{t_2}(Flow_{production}-Flow_{consumption}+Flow_{import}-Flow_{export}-Flow_{recycling}-Flow_{disposal})dt \tag{1}$$

The time period in the MFA, t_1 to t_2, is from the end of one year to the end of the next year and the flows are thus given as flow rates per year.

This equation for calculating stock changes is only applicable when all the data, with the exception of reuse/recycling and disposal flows as they are assumed to be minor, are available. However, it is found in this study that most industrial and governmental statistics do not have data on the consumption flows, or flows into use. Therefore, stock changes have to be inferred by other means.

Figure 2.2 shows a scenario in an upstream supply chain where two adjacent material stocks are linked by a transformation process with a material conversion co-efficiency of ε_i. Due to the efficiency of current transformation technology, it is assumed that the amount of stock decrease due to disposal and recycling/reuse can be ignored. It is also assumed that there is only one process that can transform one material into other. As the material from the upstream supply chain is still in a form that cannot be used by end-consumers without further downstream processes, it is also assumed that all the demand for an upstream material is generated from a downstream production process.

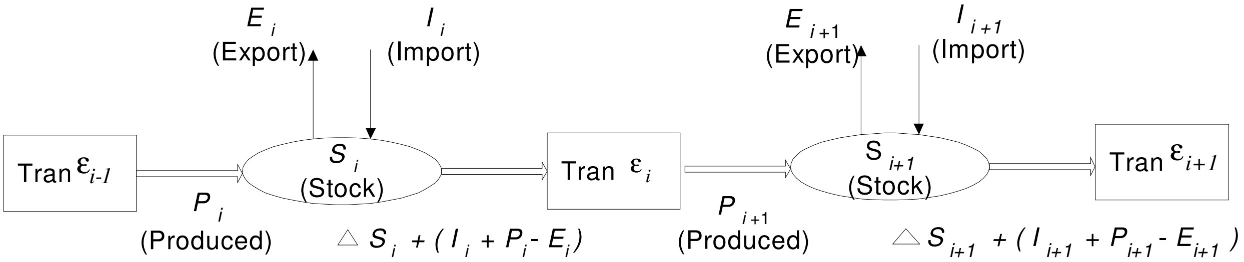


Figure 2.2 Model for inferring stock change

The total input of a transformation process *i* is, therefore, expressed as:

$$Input_i = P_i + I_i - E_i + \Delta S_i$$

where P_i is the production of material *i* in the UK, I_i is the import of material *i*, E_i is the export of material *i*, ΔS_i is the amount of material *i* taken from the stock, i.e. the industrial and commercial stocks. The output of the process *i*:

$$Output_i = P_{i+1} = \varepsilon_i \, Input_i = \varepsilon_i \, (P_i + I_i - E_i + \Delta S_i)$$

where ε_i is the material conversion yield rate, i.e. defined as the quantity of material leaving a process expressed as a fraction of the material entering. Then

$$\Delta S_i = P_{i+1} / \varepsilon_i - (P_i + I_i - E_i) \qquad (2)$$

With this model, the various types of stocks of a material holding within a supply chain can be inferred.

In many MFA studies, however, stock changes have been ignored or assumed to be depleted over the course of the year (Spatari *et al.*, 2002), because economic transformation processes can be very complex and the documentation of the in- and outputs and stock is often incomplete (Ayres and Ayres, 1999). When there are records of stocks, they are usually recorded in financial terms. According to a survey carried out for the metal supply chain in the UK in 2001, the average stock turns[6] per year in the steel sector is about 5-6 (Taylor *et al.*, 2001). The cost of the average stock held per year accounts for around 20% of cost of goods sold per year in the steel sector, and around 15% in the aluminium sector. Some environmental studies comparing low-inventory production systems with high-inventory ones have demonstrated that it is possible to reduce the wasted energy and materials that are associated with reworked and mislaid or damaged components in poorly organised production systems (Warren *et al.*, 2001).

2.3 Inferred recycling rate

One important aim of the analysis is to obtain a robust estimate of prompt scrap flow and the most elusive material flow in the iron and steel and aluminium cycles: the generation of old scrap contained in producer and consumer goods leaving the use phase. With enough information about these flows and the changes of the scrap stock it is possible to assess the level of closure of the UK iron/steel and aluminium cycles, i.e. the recycling rates of these metals. Scrap from the stock of prompt and EOL scrap is recycled domestically, exported, or lost from the economic system, typically through landfill. If scrap is exported, it is assumed that it will be recycled abroad and is counted as recovered rather than lost. The UK recycling rate that is used in this study, therefore, is defined as the yearly consumption of prompt and EOL scrap in UK iron/steel and aluminium production, minus scrap imports, plus scrap exports, divided by the yearly release of UK prompt and EOL scrap:

$$\text{Recycling rate} = \frac{\text{Yearly UK prompt and EoL scrap consumption - imports + exports}}{\text{Yearly arisings of prompt and EoL scrap in the UK}} \tag{3}$$

2.4 System modelling for the MFA: EOL flow

One important aim of the MFA is to obtain a robust estimate of the most elusive material flow in the iron and steel and aluminium cycles: the generation of old scrap contained in producer and consumer goods leaving the use phase. In order to estimate this, the time delay of goods in use has to be taken into account. The estimated EOL scrap arisings can then be compared to documented recycling rates in order to assess the level of closure of these materials cycles in the UK, that is, how much scrap is returned to the production and use system and how much is lost. Since documented scrap consumption and trade data do not discriminate between prompt and EOL scrap, the system has to include production and consumption of prompt scrap as well. The general methodology for estimating the flow of end-of-life scrap is given here.

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[6] Stock turn is the number of times an organisation replaces its stocks during a period, usually measured annually. It is calculated by using total annual sales divided by the total inventory value (everything from components to WIP to finished goods). It is the reciprocal of the mean residence time of material in stock.

In the system, the stocks of iron/steel and aluminium contained in new goods are fed by the outputs from the UK manufacturing sectors, calculated from their iron/steel and aluminium consumption, and by imports of new iron/steel and aluminium containing goods. The flows that leave this stock are exports and the new goods that enter the use phase in the UK. The stocks of new goods in the UK are assumed to be constant, which allows calculation of the iron/steel and aluminium flows into the use phase once the inflows from manufacturing and the trade flows are known. The inflow of iron/steel and aluminium to the use phase in the UK, therefore, is the same inflow to the new goods stocks. The use phase can clearly not be modelled as an instantaneous process. New goods enter the stock in use and remain there according to their range of service lives, i.e. their residence time distribution. Their use gradually depreciates the value of the goods until they leave the use phase as EOL scrap.

The approach used to estimate flows out of the stock of goods in use is adapted from the theory of residence time distributions in chemical reaction engineering. The essential elements of this theory are summarised in Appendix 2.1. The distribution of service lives is described by the function $E(t)$: the fraction of EOL goods which were in use for times from t to $(t+dt)$ is $E(t)\,dt$. If time is measured not as a continuous variable but as multiples of a fixed interval, one year in the present work, then the fraction of EOL goods which were in use for k intervals (years in this study) is denoted E_k.

In this study, a number of different sectors are considered for goods in use. Each sector is distinct from the others, so that goods flow through the sectors in parallel and emerge as EOL scrap (see Figure 2.3). Consider any sector, numbered i. Of the goods which entered this sector at time t, a fraction $E_i(\tau)d\tau$ has service life from τ to $(\tau+d\tau)$ and therefore emerges as EOL scrap in the time interval from $(t+\tau)$ to $(t+\tau+d\tau)$. If the rate of entry of new goods into the sector is $in_i(t)$, then the rate of arisings of used goods as EOL scrap is

$$out_i(t) = \int_0^t in_i(t-\tau)E_i(\tau)d\tau \qquad (4)$$

In general, the residence time distributions, E_i, will differ between the sectors.

Summing over the I distinct sectors, the total rate of arisings of EOL scrap is

$$out(t) = \sum_{i=1}^{I} out_i(t) = \sum_{i=1}^{I}[\int_0^t in_i(t-\tau)E_i(\tau)d\tau] \qquad (5)$$

In terms of the discretised distributions, equation (5) takes the form

$$out_{i,k} = \sum_{j=1}^{k-1} in_{i,(k-j)}E_j \qquad (6)$$

where $out_{i,k}$ is the EOL scrap arising from sector I in year k and $in_{i,l}$ is the flow of new goods into the sector in year l. Summing over all sectors,

$$out_k = \sum_{i=1}^{I} out_{i,k} = \sum_{i=1}^{I}[\sum_{j=1}^{(k-1)} in_{i,(k-j)}E_j] \qquad (7)$$

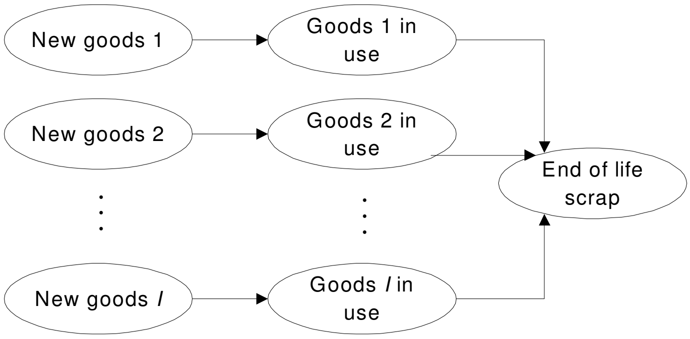


Figure 2.3 Model for EOL scrap estimation

2.5 Life span distributions

In the study three lifespan distributions have been used for each goods category to yield the release of EOL scrap: no distribution, i.e. a fixed number of years; a Weibull distribution; and a lognormal distribution. However, due to a lack of information on the actual distributions of the life spans, only information on the average lifespan figures has been obtained for each goods category. Consequently, the Weibull and lognormal distribution do not reflect any real lifespan distribution data, but give a general distribution of the average lifespan figure that have been collected for each goods sector. In the case where minimum and maximum lifespan values for a goods sector have been available, a corresponding shape of the curve has been chosen to model this.

2.5.1 Weibull distribution

The Weibull distribution is a commonly used distribution to simulate life expectancies of products. It is a flexible distribution in that it can attain many different shapes depending on the shape parameter β. The distribution used in this analysis is the two-parameter Weibull distribution. The probability density function (pdf) of this distribution is:

$$f(t) = \frac{\beta}{\eta}(\frac{t}{\eta})^{\beta-1} e^{-(\frac{t}{\eta})^{\beta}}$$

where

t = lifespan, $t \geq 0$
η = scale parameter, $\eta > 0$
β = shape parameter (or slope), $\beta > 0$

The scale and shape parameters used to produce the pdf for each goods sector in the analysis are given in Table 2.1. The parameters are not derived from real lifespan data, but have been chosen to generate a likely shape of the curve based on information from the industry as explained in section 3 and 4.

2.5.2 Lognormal distribution

A variable t is lognormally distributed if y=ln(t) is normally distributed with “ln” denoting the natural logarithm. The lognormal distribution is commonly used for analysis of cycles-to-failure in fatigue, material strengths, particle size in a powder, etc. The distribution used in this analysis is the two-parameter lognormal distribution. The probability density function (pdf) for this distribution is:

$$f(t) = \frac{e^{-((\ln(\frac{t}{m}))^2 / (2\sigma^2))}}{t\sigma\sqrt{2\pi}}$$

where

t = lifespan, $t \geq 0$
m = scale parameter, $m > 0$
σ = shape parameter, $\sigma > 0$

The scale and shape parameters used to produce the pdf for each goods sector in the analysis are given in Table 2.2. Again, these parameters are not derived from real lifespan data, but have been chosen to generate a likely shape of the curve based on information from the industry as explained in Sections 3 and 4.

Table 2.1 Weibull distribution parameters used in modelling of scrap arisings:

Weibull distribution parameters used in modelling of iron and steel scrap arisings:

Goods category	Mech.	Elect.	Ship.	Vehi.	Struct.	Metal.	Cans.	Boilers.	Other.
η in Weibull	16	17	63	14	63	18	1	14	26
β in Weibull	5	5	5	5	5	2	2	2	5

Weibull distribution parameters used in modelling of aluminium scrap arisings

Goods category	Transport	Construction	Engineering	Packaging	Consumer durables	Other
η in Weibull	14	37	18	1	8	10
β in Weibull	5	5	5	2	5	5

Table 2.2 Lognormal distribution parameters used in modelling of scrap arisings:

Lognormal distribution parameters used in modelling of iron and steel scrap arisings:

Goods category	Mech.	Elect.	Ship.	Vehi.	Struct.	Metal.	Cans.	Boilers.	Other.
m in lognormal	15	16	63	13	63	13	1	10	25
σ in lognormal	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.2	0.2

Lognormal distribution parameters used in modelling of aluminium scrap arisings

Goods category	Transport	Construction	Engineering	Packaging	Consumer durables	Other
m in lognormal	14	37	18	1	8	10
σ in lognormal	0.5	0.5	0.5	0.5	0.5	0.5

As an example, Figure 2.4 shows the lifespan distributions using a Weibull and Lognormal distribution used in the analysis for the goods category vehicles.

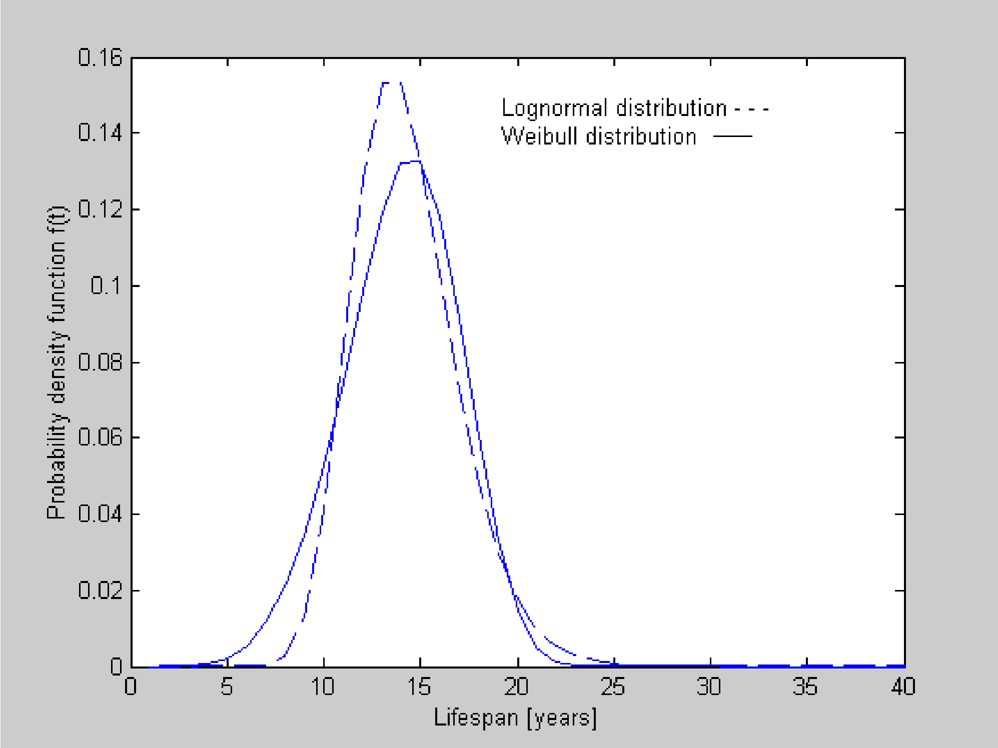


Figure 2.4 Example of probability density function (pdf) of the life span for vehicles using a Weibull distribution (η =14 and β =5) and a Lognormal distribution (m =13 and σ =0.2)

3 IRON AND STEEL MATERIAL FLOW ANALYSIS

3.1 Introduction

In this section, the supply chain systems for iron and steel in the UK will be explained. Material categories and transformation processes will be elaborated and the material flows will be examined.

3.2 Systems description

The system model of iron and steel is shown in Figure 3.1. An important feature of the supply chain for both iron and steel and aluminium is the fact that a considerable amount of scrap is fed back into the system as secondary raw material. In fact, iron and steel is the most recycled material in the world, with more than 435 Mt recycled in 2001 (IISI, 2002). For this reason the iron and steel supply chain is sometimes also called the iron and steel cycle (Birat *et al.*, 1999).

3.2.1 Material categories

Iron ore: Iron ore is extracted from the natural environment and is the primary resource for iron and steel production. Its global supply can be regarded as essentially unlimited since iron is the second most frequent metal in the earth's crust after aluminium with an average crustal abundance of 5.8% (Meadows *et al.*, 1992). Nevertheless, some countries such as the UK have no or little economically viable stock and therefore rely on imports of high-grade ores for steel production.

Home scrap: Home scrap consists of scrap that is produced in iron and steel foundries and mills as a by-product of their operations. It is typically recycled internally and is called internal circulating scrap by the industry.

Iron and steel prompt and end-of-life scrap: Prompt scrap is generated when steel is cut, drawn, extruded or machined during the fabrication and manufacturing of goods (vehicles, construction, packaging etc.). Because of its known composition and low contamination with other materials it is usually very easy to recycle and therefore experiences very high recycling rates. End-of-life (EOL) scrap arises from the iron and steel contained in final goods coming out of the use phase, like old vehicles, steel beams and sections from demolished buildings and electrical and electronic equipment waste. Most EOL products contain a mix of different materials and the separation of the iron and steel content is an important issue if it is to be recycled.

A considerable amount of scrap is recycled and serves as secondary resource for iron and steel production. The contribution of crude steel produced from scrap to the total UK crude steel production over the years is shown in Figure 3.2.

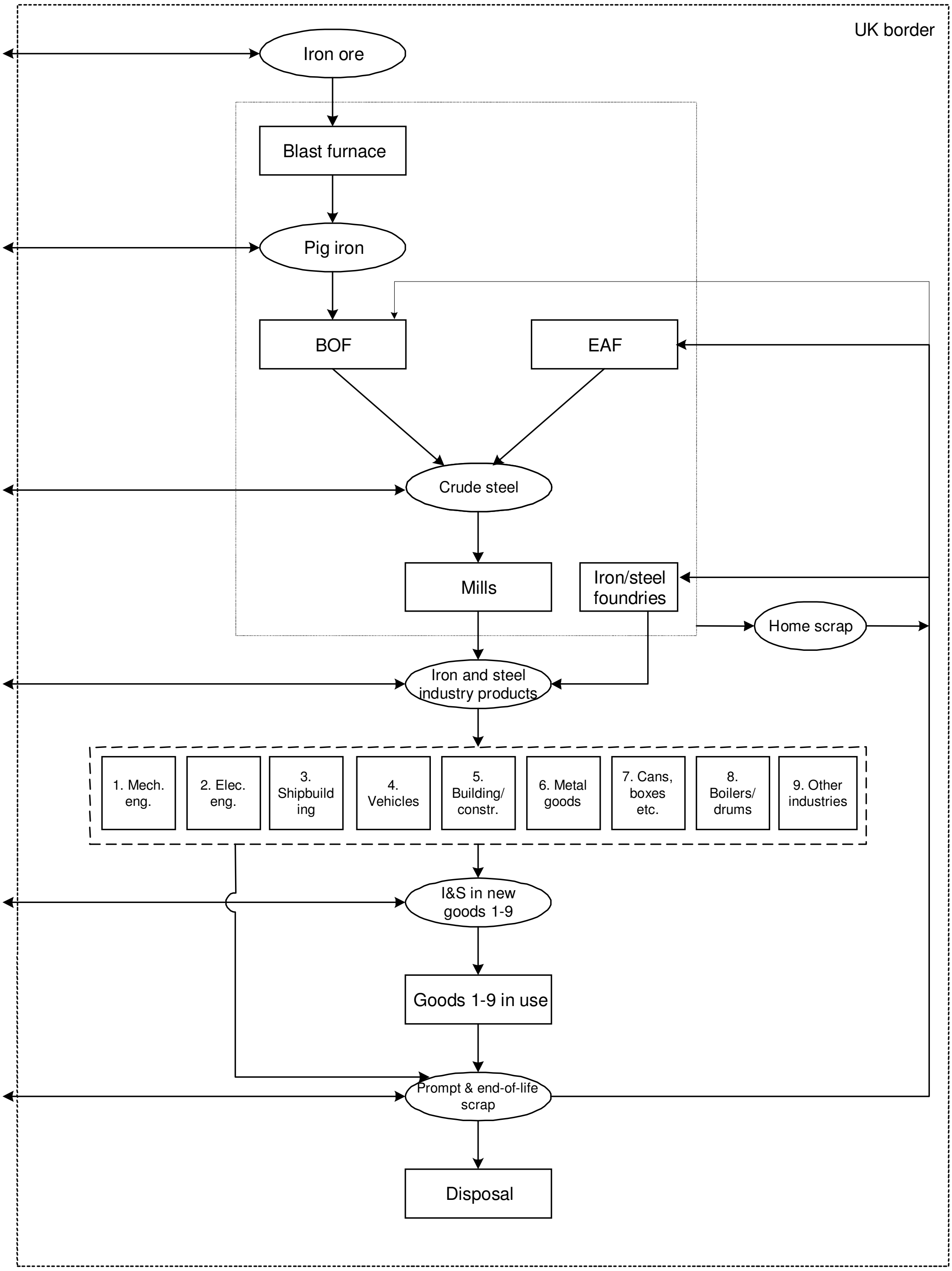
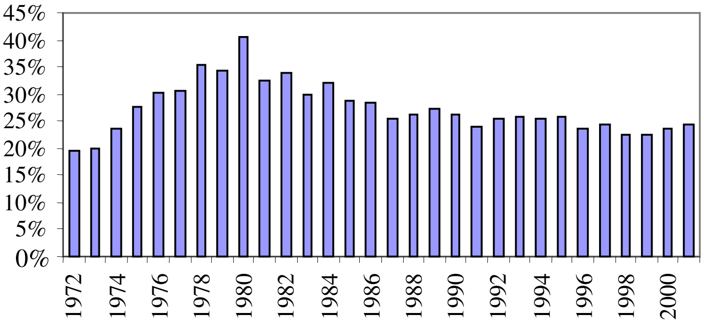


Figure 3.1 System overview of iron and steel flows in the UK



Source: ISSB Annual Statistics (2001) and previous issues

Figure 3.2 Percentage of crude steel produced from scrap

Pig iron: Iron ore is converted into pig iron in the blast furnace (BF). Pig iron contains about 4-5% carbon and is therefore brittle and unsuitable for inclusion or rolling into other products. Most pig iron is produced for further processing into steel, but is also used for castings where its rigidity and machineability are important.

Crude steel: There are two ways to produce steel. One is the integrated route, where hot pig iron is the main input material (80%) into the basic oxygen furnace (BOF). The other is the electric-arc furnace (EAF), where iron and steel scrap is the main input, although cold pig iron or direct reduced iron (DRI) may be used. Two EAF routes exist: a low-cost route producing lower grade plain-carbon steel products, like rebar, beams and sections, for which cleanliness is not critical; and a more flexible but more expensive route producing higher-specification products. The former route declined, to disappear in 2001, although limited production by this route has now restarted. Hot and liquid crude steels from the BOF or EAF are formed by one of two processes: continuous casting which is the normal route for billets, blooms and slabs and ingot casting, which as the name indicates, produces ingots. The percentage of crude steel from the continuously cast route has increased from less than 10% in the 1970s to more than 95% in 2000 (ISSB, 2000). Whichever casting route is followed, the continuously cast or ingot product is rolled to its final product shape (Williams, 1983). The crude steel can be in liquid form when it is continuously cast and then sent to mills nearby for final processing. It can also be produced in solid form, such as slabs, billets, blooms and ingots, which are shipped to other plants or abroad. The data for crude steel stock denote the solid form.

Iron and steel industry products: This category comprises all the finished iron and steel leaving iron and steel producers in the form of castings, rods, sections, plates, sheets, etc. Iron and steel are distinguished by their carbon content, between 2-5% for cast and pig iron and 0.05-2% for steel (Williams, 1983). Steel industry products include all steel qualities within the carbon and alloy groups. Steel can go through a multitude of processes, being gradually converted from a raw material, like pig iron or crude steel, into a finished component for a final application. The distinction between production and fabrication is not sharp. For our purposes it is less important to consistently define the steel product sub-categories that separate production from fabrication than it is to avoid double counting, i.e. counting the same steel first as cold rolled sheet and then again as tinplate within the iron and steel product category.

New goods: New goods are all the physical products that are manufactured and fabricated to be used in the economy by their private, corporate or governmental owners. They typically contain a variety of components made of various pure and composite materials. The category of *iron and steel contained in new goods* accounts only for the iron and steel that is embodied in all the different new final goods that are about to enter the use phase in the UK or abroad.

3.2.2 Processes

Production

In the UK, steel is produced in the blast furnace/basic oxygen furnace route at integrated steelworks, and in electric arc furnaces at so-called mini-mills. There are three integrated steelworks in the UK, all owned by Corus, at Port Talbot, Teeside, and Scunthorpe. There are a larger number of mini-mills, owned by Corus and other firms. Iron input into the integrated route is roughly 85% from ore and 15% from scrap (predominantly home scrap). EAFs in the UK rely on scrap (mainly prompt and end-of-life scrap) as a source of iron for the lower specification products, whereas the more flexible BF/BOF route produces higher value products. Most of the pig iron and scrap is used in steelmaking, while a small proportion is used in iron and steel foundries to make casting products. All iron products in the UK are castings and therefore come from foundry industries. The UK iron and steel foundries used to consume a mix of pig iron from blast furnaces and scrap but now use almost exclusively scrap. Figure 3.3 shows the three production routes in some detail.

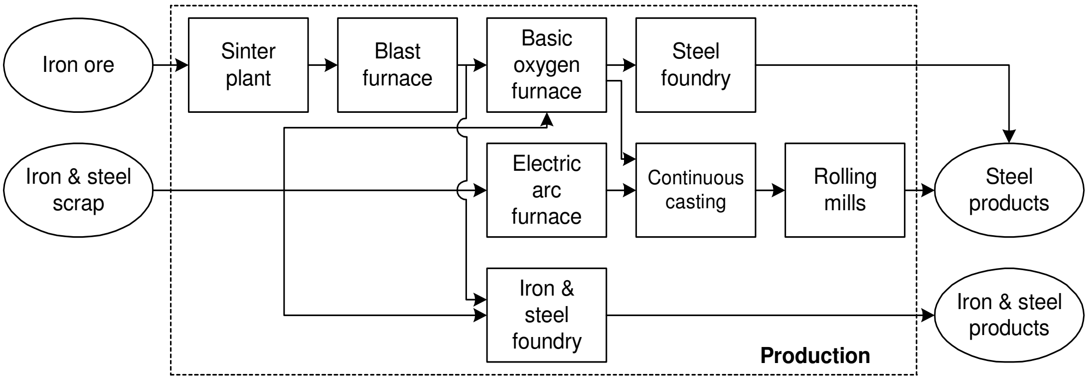


Figure 3.3 Iron and steel production routes in the UK

The ore used in the UK is usually sintered before it is fed into the blast furnace. In the sinter plant iron ore, limestone, coke and water are mixed to produce sinter, which is a porous material with a large surface area to volume ratio (Corus, 2000). In the blast furnace sinter is layered with limestone, which helps to form impurity-absorbing slag, coke and powdered coal. A hot air blast provides the oxygen to transform the coke and coal into carbon monoxide, which is the main reducing agent. The blast furnace is operated continuously and consumes about 60% of the overall energy demand of integrated steelworks. The furnace produces slag and liquid pig iron, which is transported in torpedo ladles to the BOF.

The purpose of the BOF is to reduce the carbon content of the pig iron from around 4% to less than 1%; to remove remaining impurities; and to add desirable foreign elements. Scrap is added as cooling agent since exothermic oxidation processes heat the process above its requirements. After the BOF the molten steel is refined to improve its quality, a process usually referred to as secondary metallurgy. When the desired quality of the steel is achieved the liquid is cast. The final production stage is the rolling mill, which is the second most energy demanding process of integrated steelworks and consumes about 25% of the overall energy demand. This is mainly due to the re-heating of the steel.

EAFs in the UK rely on scrap as iron source. EAFs are also capable of using directly reduced iron (DRI) from ore as an alternative input but this is not practised in the UK. Other inputs are electricity, the main energy source, and lime and dolomite, which are used as flux for the slag formation. The furnaces are operated in batches and charged with baskets of scrap and lime or dolomite for each batch. Boring down electrodes into the scrap initialises the melting. Fuels, such as oils and natural gas, and oxygen are injected into the furnace to assist the melting. Oxygen also decarburises the melt and removes undesired elements such as phosphorus, silicon, manganese and sulphur.

The EAF is often followed by secondary metallurgy, which is more complex for high alloy and stainless steels than for lower quality steels. When the desired composition of the steel is reached the molten steel is cast. Today, most of the steel is cast continuously, but ingot casting is also applied for some grades and applications. Like steel from the BOF route, after casting the steel is transferred to the rolling mills where the steel products are rolled into their final shapes.

Iron and steel foundries use scrap and pig iron as input. Today, the pig iron consumption of UK foundries is negligible. According to ISSB statistics, the percentage of pig iron used in foundries reduced from 7-8% in the 1970s to 1-2% in early 1980s. The metal input is heated in a furnace and brought to the required material composition. Once the right composition and temperature is reached the liquid metal is poured into a mould, which can be made from sand, plaster, ceramics or metal. The metal then cools and solidifies, and the mould is removed revealing the raw casting. The raw casting is shotblasted, i.e. its surface is smoothed with a high pressure jet of particles, and its gates, risers and sprues are separated. The casting is finally taken to a grinding station where the parting line and any other undesired unevenness or protrusions are removed.

Fabrication and manufacturing

Integrated steelworks, mini-mills and foundries produce iron and steel products like plate, sheet, coil, rod, sections and castings. New goods manufacturers however normally do not use these products directly, but they go through tiers of component manufactures and subassemblies. Research on the British metal supply chain identified a four-tier steel supply chain structure for automobile manufacturing: steel mills, primary/secondary converters, first-tier component producers and automobile original equipment manufacturers (Taylor, 2001). Another example is steel sections for construction. The steel sections are processed by section fabricators, which create a detailed technical drawing of the steel structure to be erected and then drill all the holes and weld on all the plates and struts that the sections require for assembly (March, 2003). After these sections are coated they are ready to be erected and to become part of the overall construction, say a building, which constitute the new goods. It is also important to note that roughly half of all domestic deliveries by UK steel producers go to stockholders, as do many of the imports. Many fabricators therefore purchase their iron and steel not directly from the steel producers but from stockholders instead, which turns stockholders into important agents of the iron and steel supply chain.

The manufacturers assemble the components from the fabricators into a new good, such as a car, a washing machine or a personal computer. A manufacturer typically requires many different components, some with and some without iron and steel content, from various fabricators. Depending on the level of vertical integration a manufacturer may also fabricate some components in-house and thus become a direct consumer of iron and steel industry products. A new good typically consists of a multitude of different materials, combined on either component or product level, and therefore only a certain percentage of its total mass is iron and steel. For example, the average ferrous metal content by weight is currently 68% for a vehicle (Waste Watch, 2003); 60% for a washing machine; and 30% for a personal computer (ICER, 2000).

The ferrous metal content of new goods varies not just across product types but also with time as materials substitution occurs. For vehicles, for example, it has been consistently decreasing over time. The amount of scrap that is generated during fabrication and manufacturing, called prompt scrap, varies significantly for different fabrication and manufacturing processes. Most of the prompt scrap is uncontaminated and therefore easy to recycle, which results in very high prompt scrap recycling rates. The new goods are either exported or offered on the domestic market, where they compete with imported goods of the same type.

Due to the wide ranges of goods, manufacturing processes and industrial sectors these processes belong to, new goods are grouped into nine main categories according to the industries they come from. Table 3.1 shows these categories, which are elaborated further in Appendix 3.1. The difficulty of tracking the iron and steel flows at this stage of the supply chain increases when considering the iron and steel flows within and between different goods manufacturers and the possibility of double counting. For example, most of the products from the manufacture of parts and accessories for motor vehicles will be delivered to a manufacturer of motor vehicles and assembled into a vehicle. The rest will be delivered as service parts for vehicle maintenance to the end consumer market. Therefore, the parts that go to motor vehicle manufacture have to be deducted from the total flow to avoid double counting, as these parts will be accounted for in the vehicles. Double counting is more difficult to handle when material moves between totally different industry categories. In order to avoid double counting, it has been assumed that the iron and steel that goes into each of the nine categories are used in goods from that category.

Table 3.1. Categories of new goods based on manufacturing sectors

	New goods categories	**Sub-categories**	**SIC sectors involved**
1	Mechanical engineering and plant	Machinery and Equipment	28.22, 29.11, 29.12, 29.13, 29.2, 29.3, 29.4, 29.5
		Other Mechanical Engineering	28.5, 29.14, 29.6
		Other Industrial Plant	part 28.3
2	Electrical engineering	Domestic Electrical Appliances	29.71
		Other Electrical Engineering	30, 31.1, 31.2, 31.3, 31.4,
3	Shipbuilding		35.1
4	Vehicles	Motor Vehicles	31.61, 34
		Other Transport	35.2, 35.3, 35.4, 35.5
5	Steelwork and civil engineering	Structural Steelwork	28.1
		Building and Civil Engineering	45
6	Metal goods	Metal Furniture	part 36.1
		Other Metal Goods	28.6, 28.74, 28.75, 29.72
7	Cans and metal boxes	Cans and Metal Boxes	28.72
8	Boilers, drums and vessels	Vats, Tanks and Drums	28.21, 28.71
		Boilers and Associated Plant	part 28.3
9	Others	Coalmining	10.1, 10.2
		Oil and Gas Extraction	11
		Wire Drawing	27.34, 28.73
		Forging and Stamping	28.4
		Cold Forming	27.33
		All Other Consumers	All other codes

Use

New goods are manufactured for sale to end customers. The use of new goods containing iron and steel is thus the ultimate reason for and destiny of the iron and steel flow through production, fabrication and manufacturing. Many of the new goods manufactured in the UK are exported, and many of the new goods in use in the UK come from imports. It is therefore vital to account for trade in order to establish the quantity and quality of new goods entering use in the UK. The outflow of EOL products is a consequence of the limited life span of new goods. For this reason the characteristics of the use phase are very distinct from those of the other processes in production and manufacturing.

First, the material transformations of the use phase are usually unintentional and an effect of product use. Three types of transformations are relevant for the industrial ecology of materials in the use phase: physical alteration, contamination, and dissipation. Product use can of course result in a mix of these three transformations. The two most common physical alterations for products containing iron and steel are corrosion and radioactive contamination. Corrosion leads to the dissipation and loss of the iron, and radioactive contamination renders the material unfit for recycling. Contamination of a metal can arise from alloying with other metals. It can also occur during the use phase (e.g. food in tin cans), or from incomplete separation from other components in an EOL good (e.g. copper cables in cars). Recycling activities need to separate the desired material from the others without unacceptable environmental impacts and within reasonable cost. During use goods can also dissipate in the environment, with or without physical alteration, and cannot be collected for disposal or recycling (Ayres and Simonis, 1994). The proportion of dissipative uses is substantial for some metals like zinc, while it is small for others like copper, and negligible for iron and steel (Ruth, 1998; Graedel *et al.*, 2002).

Second, unlike most other processes, use cannot be modelled as an instantaneous transformation of material from input stock into material which is added to the stock of output. The time-dependent MFA, like many others, uses time increments of one year. The reason for this is simply that most data are collected on a yearly basis. This generally justifies the assumption that material that enters a transformation process in one time period as input is processed and leaves it as output in the same time period. Most goods containing iron and steel, on the other hand, are used for several years, and the assumption of instantaneous transformation does not hold for the use phase. It is therefore more appropriate to model the use phase as a transformation process as well as a material stock of goods in use. Iron and steel contained in the new goods that enter the use phase becomes available as EOL scrap only after the time delay of the goods' service life. The modelling of scrap arisings will be elaborated in Section 3.5.1, using the methodology developed in Section 2.4.

3.3 Data availability and sources

The Iron and Steel Statistics Bureau (ISSB) in the UK is dedicated to the collection and publication of data on the UK iron and steel sector. It has been collecting steel industry statistics for over 100 years and is regarded as one of the world’s leading agencies on steel industry information. The UK iron and steel producers report directly to the ISSB, whose experts gather additional information from other statistics sources, like the Office of National Statistics (ONS), Her Majesty’s Customs and Excise (HMCE), and from surveys, e.g. of UK stockholders. ISSB, therefore, is the main data source for the upstream (production) material flow analysis. Data for UK production has been collated for the years 1968 to 2001, unless stated otherwise.

Iron ore, pig iron, crude steel and iron and steel industry products**:** The ISSB has data on domestic iron ore production, iron and manganese ore import, and consumption of domestic and imported ore. Manganese is a basic ferroalloy present in virtually all steel qualities. No export of iron ore is reported in the last three decades. Production of pig iron and consumption of pig iron in steel making, as well as crude steel production and production of finished iron and steel products are also given in the ISSB statistics.

Scrap: The ISSB publishes data on scrap imports and exports and scrap consumption by production process. Data on consumption by iron foundries is available from the British Metals Recycling Association (BMRA, 2003). Figures on the generation of home scrap exist, but not on the generation of either prompt or EOL scrap. The vast number of manufacturers makes it virtually impossible to collect this data directly. There is in fact no institution in the UK that attempts to estimate this important information. Robust estimates of prompt and EOL scrap arisings in the UK have therefore been obtained by the modelling approach developed in this study.

Iron and steel industry products to UK manufacturing: These products come from UK producers, UK stockholders and imports. Because the products come from these three different sources, it is difficult to generate data on the amount of iron and steel that enters each industry sector. The ISSB has data on the total amount of iron and steel that enters UK manufacturing industry, defined as ‘net home disposals’. The ISSB also has some detailed information on how much iron and steel enters each industry sector, but only for iron and steel products that are delivered directly from UK producers. For the imported iron and steel and deliveries from UK stockholders, no documentation on how much goes into each industry sector is available.

However, the ISSB has analysed the imports in terms of what type of iron and steel products they consist of and has also performed comprehensive market surveys of the stockholders in order to determine how much iron and steel is delivered to each manufacturing sector in the UK covering deliveries from all three sources. This dataset has not been used for MFA-type research before and constitutes the backbone of the present analysis. The data divide total deliveries into the nine industry sectors mentioned above (Table 3.1). The data is compiled for the years 1970 to 2000, and figures for 2000 are used for 2001. For iron and steel that goes into construction, data compiled by the Steel Construction Institute (Ley *et al.*, 2002) have been used. This construction data set covers the time period 1900 to 1975[8] and has been employed in this study, based on estimates from the industry.

Unfortunately data on consumption of cast iron in different industry sectors are not available. In the analysis it has therefore been assumed that one Mt a year of foundry iron is used in UK fabricating and manufacturing. It has been assumed that half of this is used in the production of pipes for water and gas supply (under sector 'structural steelworks and building and civil engineering'), and that the remainder is split equally between 'mechanical engineering' and 'boilers, drums and other vessels'. These assumptions have been verified by the British Foundry Association (Donahue, 2003, *pers. comm.*). Table 3.2 gives the resulting market shares for deliveries of iron and steel industry products to UK manufacturing industry in 2000.

Table 3. 2 Market shares for iron and steel in 2000 and prompt scrap rates

Goods category	Market share [%]	Prompt scrap rate [%]
Mechanical engineering	17	10
Electrical engineering	5	10
Shipbuilding	0	10
Vehicles	17	10
Structural steelwork and building and civil engineering	26	5
Metal goods	6	10
Cans and metal boxes	4	17
Boilers, drums and other vessels	4	10
Other industries	20	10

Depending on the manufacturing sector, different amounts of prompt scrap are generated from cutting, drawing, extruding or other shaping of the metal to produce final goods. In the analysis the inflow of iron and steel products to each sector has been multiplied with sector specific factors to generate the flow of prompt scrap from the fabrication and manufacturing stage. A prompt scrap rate of 10% (Aylen, 2003, *pers. comm.*) has been used for all sectors except construction and packaging for which prompt scrap rates of 5% (EC, 2002) and 17% (May, 2003, *pers. comm.*) have been used respectively. It has been assumed that these rates were constant over the time period analysed. The prompt scrap generation rates are also shown in Table 3.2.

New goods: To derive imports and exports of iron and steel contained in traded final goods, all the goods that contain iron and steel have been selected and compiled into the nine sub-categories of industry sectors and their total mass have been multiplied with

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[8] From 1900 to 1955, the construction data have been estimated using literature, UK steel consumption data and the output of UK construction from 1900 to 1955. Data from 1955 to 1975 are derived from the ISSB (ISSB, 2001).

estimated average iron and steel contents. Data for trade in new goods have been collected from HMCE for every 5 years between 1968 and 2000. The selected categories and their corresponding Standard Industry Trade Classification (SITC) codes are given in Appendix 3.2. The data have then been linearly interpolated to yield yearly values and aggregated into the nine industry sectors. In order to estimate how much iron and steel the traded goods contain, a constant average iron and steel content for each of the nine categories has been assumed by using steel efficiency coefficients produced by the International Iron and Steel Institute (IISI, 1996). The steel coefficients give the amount of steel that is required to produce one tonne of finished goods. It has been assumed that the coefficient multiplied by 1 minus the prompt scrap rate for each sector, is equivalent to the steel content in the finished goods. Table 3.3 gives the resulting steel content figures that are used in the analysis.

3.4 Analysis of iron and steel time series data

In this section, individual flows concerning an individual material category will be analysed. Upstream material production, import and export activities are eventually driven by the supply-demand mechanism in the downstream market.

Table 3.3 Iron and steel content of traded goods.

Goods category	Iron and steel content [%]
Mechanical engineering	71
Electrical engineering	30
Shipbuilding	70
Vehicles	58
Structural steelwork and building and civil engineering	100
Metal goods	85
Cans and metal boxes	100
Boilers, drums and other vessels	100
Other industries	60

In order to show the relationship between domestic production and demand, the figure for *domestic demand* has to be derived. When data are available on the consumption of a material in its downstream process, these data are used as the *equivalent to demand*. When such consumption data are unavailable, domestic demand is derived by using the definition of apparent consumption, adding imports and production and subtracting exports (IISI, 2002).

Stock changes within an individual material category will also be explored. The stock changes can be calculated if there are data for the total available material (including UK production and purchasing/imports) to a process and the actual consumption of the specified material in the downstream processes. To this end, there are available data for iron ore and scrap. In the event where there are no direct data on total availability and consumption of a material for a process, the mass balance equation (1) stated in Section 2 will be used. This applies to pig iron, crude steel and steel products.

However, stock changes need to be compared with demand in order to be meaningful. Therefore, the *stock change level* of a material category is defined as the stock change divided by the domestic demand of the material. Finally, the relationship between the flows of different material categories will also be examined to show the interactions between them.

3.4.1 Iron ore

Imports, exports and extraction: No directly reduced iron has been used in UK steel production since 1968. Ore and scrap are, therefore, the only iron resources for iron and steel production in the UK. The UK depends heavily on iron ore imports to supply its pig iron production from blast furnaces (BF) (Figure 3.4). The imported iron ore used in BF production increased from 60% in 1969 to 100% in 1993. There are no exports of iron ore.

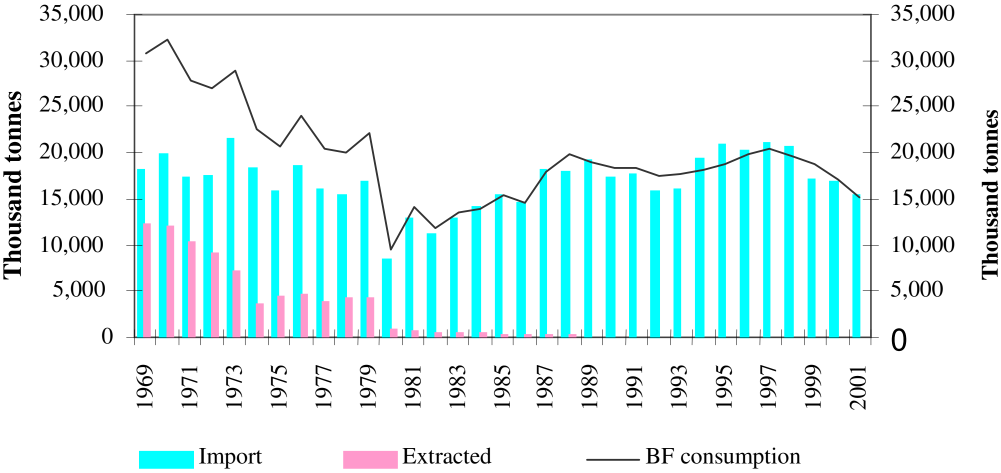


Figure 3.4 Iron ore import, domestic extraction and consumption

Stock and stock changes: There is no record of stocks of iron ore in the UK. However, stock changes can be inferred from the difference between available iron ore on a yearly basis from import and extraction and consumption of ore at the BF. Figure 3.5 indicates considerable iron ore stock changes over the last decades. Apart from consumption in blast furnaces a small amount of iron ore is also used in steel making. The level of iron ore consumption in steel making was about 240 kilotonnes (kt) before 1979 and 40-100 kt thereafter. These stock changes varied between plus and minus 10% of total consumption in iron and steel making. There is also an indication that during the time period studied, only 11 years had a stock surplus, while the remaining years had negative stock changes. According to ISSB, there are unreported stocks of iron ore at the producers' sites.

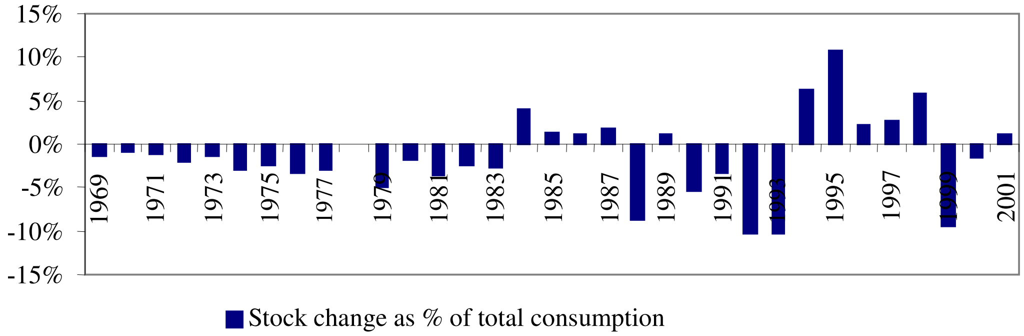
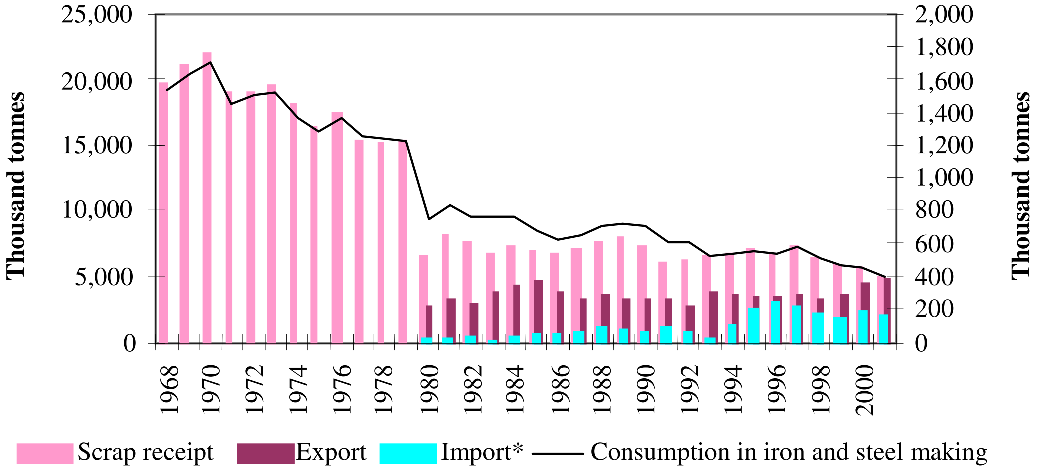


Figure 3.5 Iron ore stock changes

3.4.2 Iron and steel scrap

Imports, exports and consumption: In contrast to iron ore, there is a very small amount of scrap import to the UK. The level of imports was below 52 kt before 1986 but increased to above 150 kt from 1996 (Figure 3.6). There has been an overall and gradual increase in the scrap exports over the years despite some fluctuations. In 2001, the country imported 170 kt and exported 4.8 million tonnes (Mt) of iron and steel scrap.

However, both total scrap receipts and consumption at the iron and steel works show a sharply declining trend. The sharp drop in 1980 occurred partly because of the steel strike in that year, and partly because scrap consumption at foundries ceased to be included in the statistics. However, scrap consumption at iron foundries was about 1.3 Mt in 2001, and between 2 and 3 million in the 1980s and 1990s (BMRA, 2003), so the decline would have been apparent even without this change in data compilation.

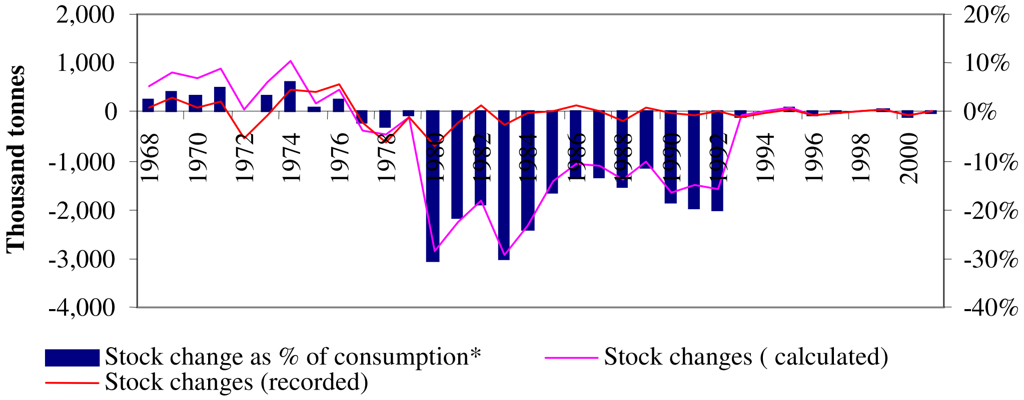


*Blue series scaled to the right hand axis, others scaled to left hand axis. No data for import and export before 1980

Figure 3.6 Scrap import, export, consumption, receipts

The difference between scrap receipts and consumption at the steel works, which makes up the scrap stock change, has over the years shown a similar pattern to that of iron ore, that is the over-consumption of scrap in the production for most of the years. There are industrial statistics on the stock change of scrap at steel works at the end of each year. However, when comparing the calculated stock change and the recorded stock changes (Figure 3.7), it appears that there is a discrepancy between the results of statistics and theoretical calculations. This is because data for stock are reported by producers only, while the calculated estimates include scrap stock held in the system by all parties. There was undoubtedly a fall in scrap stocks over the 1980-1990 period; however the exact quantity is not known.

Iron ore, scrap and overall crude steel production: As ore and scrap are the only iron raw materials for iron and steel production, the flows of greatest interest are the consumption of ore and scrap in the UK. The majority of ore and iron and steel scraps will be turned into crude steel. These data series are compared with crude steel production in Figure 3.8. Iron ore is taken to have an iron content of 62%, which is the average for all iron ore imports in 1998 (ISSB, 2001). The resulting data of total iron ore tonnage multiplied by percentage iron content is called *equivalent iron in ore* and gives the approximate amount of primary iron that enters UK production. Both consumption rates declined for the first decade. Interestingly, between 1968 and 1985 the amount of iron and steel coming from scrap was higher than the amount of iron in the consumed iron ore.



*Blue series (calculated stock change level) scaled to the right hand axis.

Figure 3.7 Iron and steel scrap stock change at the steel works

A sharp drop in both consumption rates was experienced in 1980 due to the national steel strike, which lasted three months. Iron ore consumption picked up again, and for the last 13 years it has been around 12 Mt per year. Scrap consumption, on the other hand, continued to decrease until 1986, since when it has maintained a volume of around 8 Mt per year. This signifies that for the last ten years or so, roughly 60% of the iron input into UK production came from ore. The remaining 40% of the iron input originates from scrap. For the last decade the home scrap share of scrap consumption has been around 30%.

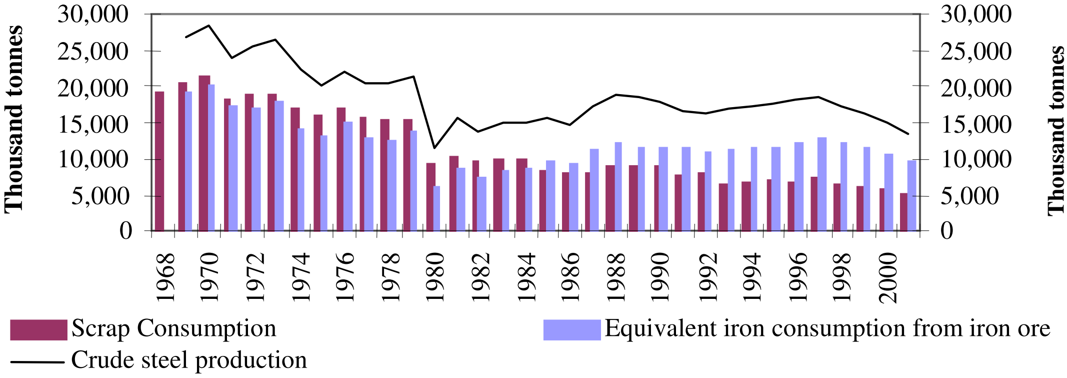


Figure 3.8 Consumption of iron in ore and iron and steel scrap in UK steel making

3.4.3 Pig iron

Production, imports, and exports: More than 95% of the imported and extracted iron ore is consumed in BF to produce pig iron. Pig iron production maintained a level of around 15 Mt per year between 1969 and 1973, before declining to about 12 Mt in 1980, when a quick drop to 7 Mt occurred, again largely due to the steel strike. There was a stable production rate of around 12 millions tonnes during the period 1987 to 2000. However, there was again a decrease in 2001 to about 10 Mt. On average, about 60% of the amount of ore will have been converted into pig iron in the BF. The conversion rate is illustrated in Figure 3.9, while the production, export and import time series are shown in Figure 3.10.

When compared with domestic production (Figure 3.10), trade of pig iron is insignificant. Pig iron imports have maintained a mean level of 150 kt per year with a variance of 70 kt. Exports were below 60 kt between 1968 and 1993. Since 1993, exports dropped to about 10 kt. In 2001, only 6.7 kt were exported from and 160 kt imported into the UK. More than 90% of the pig iron produced will be delivered to the downstream steelmaking process, while the rest is delivered to foundries or stored. Pig iron deliveries to foundries went from 7% of production in 1968, to 2% in 1992, after which there are no further records of pig iron deliveries to foundries.

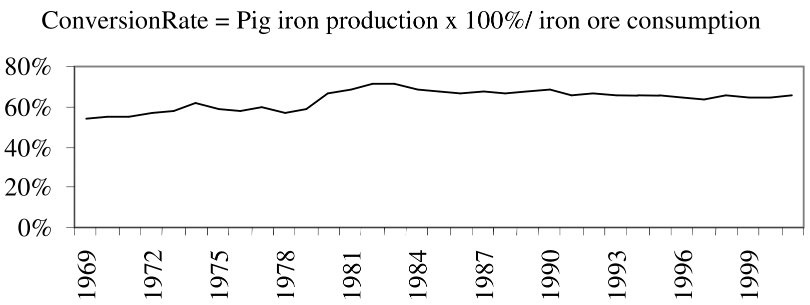
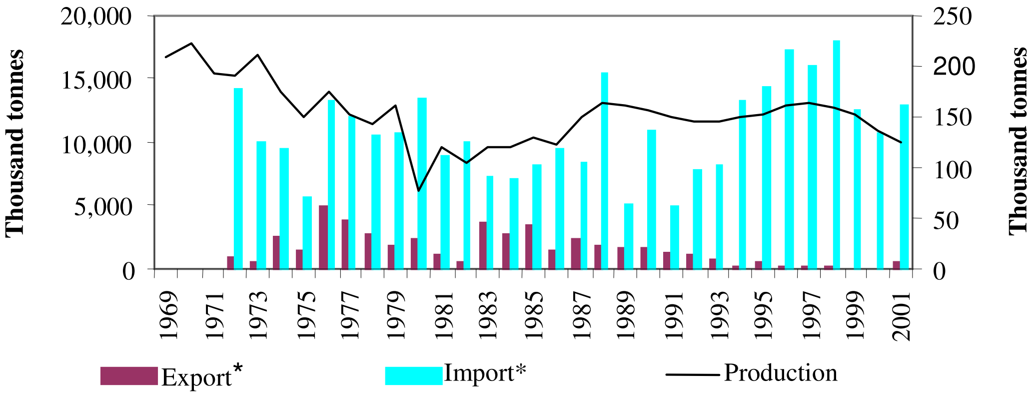


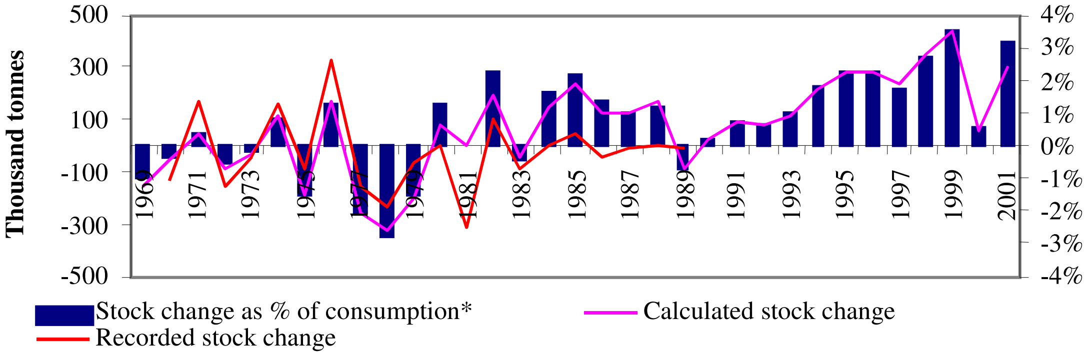
Figure 3.9 Conversion rate from iron ore to pig iron



*trade scaled to right hand axis, production scaled to the left hand axis

Figure 3.10 Pig iron production, export and import

Stock changes: Data on pig iron stock are available from the ISSB for the period 1968-1989, but since 1989 pig iron stock data were no longer recorded in the statistics. After 1989, stock changes have to be calculated using the equation (1) in Section 2. Figure 3.11 shows the calculated and recorded stock changes. The figure displays a discrepancy between these two variables. A possible explanation is that both pig iron producers and crude steel producers will hold pig iron stock as finished goods and raw material respectively. The level of stock change was low, about ± 4% of the production. The calculated stock change series suggests that there has been almost a constant pig iron accumulation in the system since 1981. However, it is impossible to establish whether this is a real trend in stock, or is an artefact introduced by deficiencies in the data. For the purpose of this MFA, the inferred stock changes are assumed to be real.



*Blue series scaled to right hand axis, consumption is derived as import plus production minus export.

Figure 3.11 Pig iron stock change in the UK

3.4.4 Crude steel

Production, import and export: Apart from the small quantities of pig iron that go to iron foundries, more than 92% goes to crude steel making in the integrated routes. The integrated routes accounted for about 60-70% of total crude steel output in the country with the remaining part coming from electric arc furnace (EAF) using scrap. Crude steel production (Figure 3.12) has a mean level of approximately 20 Mt per year with a variance of 7 Mt between 1968 and 2001. It seems that after the big decline during the steel strike in 1980 there was a slow pickup in crude steel production, despite small peaks and troughs, until 1997. From 1997 to 2001 there was a steady decrease from 18.5 Mt in 1997 to 13.5 Mt in 2001.

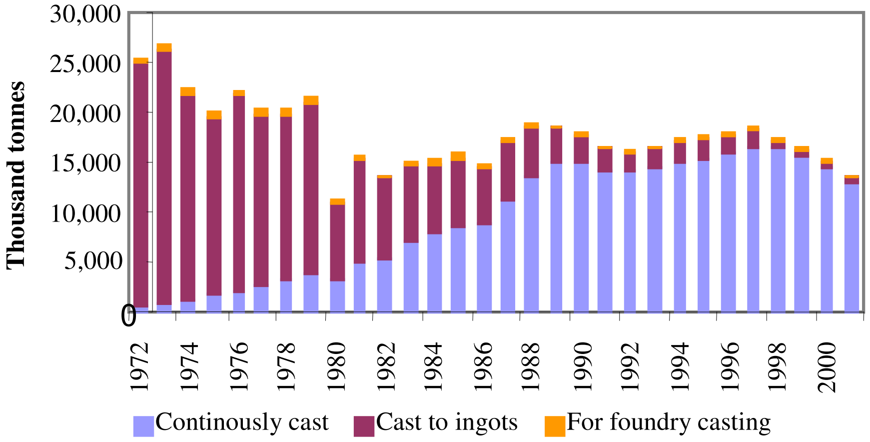


Figure 3.12 Crude steel cast methods

Of the hot liquid crude steel from both EAF and BOF, only a tiny proportion will go to foundries to produce cast products. The majority of crude steel is cast into ingots or continuously cast into billet, slab or bloom. Most crude steel is now continuously cast, from 2% in 1970 to 96% in 2001, due to its material efficiency over ingot casting.

Like pig iron, there is a small amount of crude steel import and export, at most 5 and 7 per cent of the production respectively. More crude steel was imported than exported during 1978 to 1983, although there was also an increasing trend in the export (Figure 3.13). However, during 1983 to 1997, the country had significantly higher levels of export than import. In 1987 and 1988 the country saw the highest crude steel exports since 1978, of about 1.6 Mt. Export then dropped sharply in 1998 to about the same level as import. In 2001, the country exported 0.75 Mt and imported 0.4 Mt of crude steel.

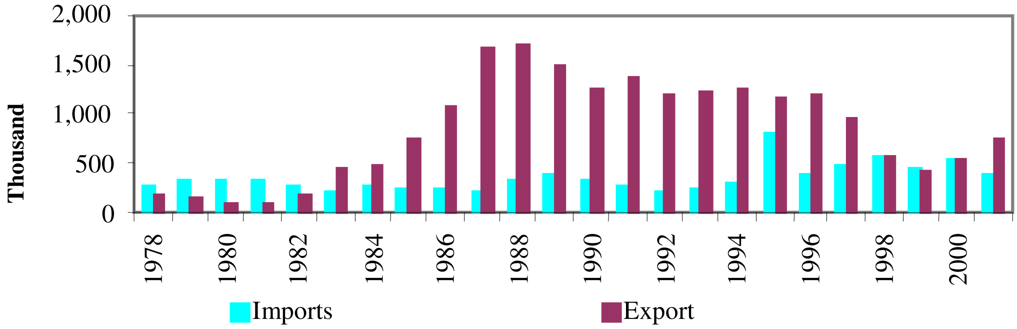


Figure 3.13 Crude steel imports and exports

Stock changes: There is no record of crude steel stock from the statistics. There are also no data about crude steel consumption in steel product production. Therefore, it is difficult to analyse the stock changes of crude steel by only looking at data concerning crude steel. Crude steel stock change, therefore, has to be inferred by looking at the steel production and the material co-efficiency in converting crude steel into steel products using equation (2) in Section 2.2.

In order to infer the stock changes of crude steel, the yield rate of converting crude steel into steel products has to be identified. Different steel products such as coils, plates, sections and rods have different yield rates, ranging between 78 and 98 per cent (IISI, 1997). These yield rates refer to the situation in 1991; however, yield rates improve over time due to technological improvements. Therefore, it is difficult to choose a representative yield rate for all the mill processes. Nevertheless, the IISI has used a method[9] to derive the conversion rate between crude steel and steel products when converting the finished product weight into crude steel equivalents.

Using this method, the inferred conversion rate of crude steel into steel products for UK steelworks is illustrated in Figure 3.14 and the stock changes of crude steel are shown in Figure 3.15. Figure 3.15 shows considerable depletion of crude steel stock starting in the 1980s. The stock change trend mirrors that of conversion rate: the higher the conversion efficiency in steel product production, the higher the depletion of crude steel stock. Around 1 Mt of crude steel was depleted from the stock in 2001.

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[9] Steel statistics year book (http://www.worldsteel.org/media/ssy/iisi_ssy_2002.pdf), to convert finished product weight into crude steel equivalent, the weight of finished product is multiplied by 1.3/(1+0.175c), where c is the domestic portion of crude steel that is continuously cast in a year.

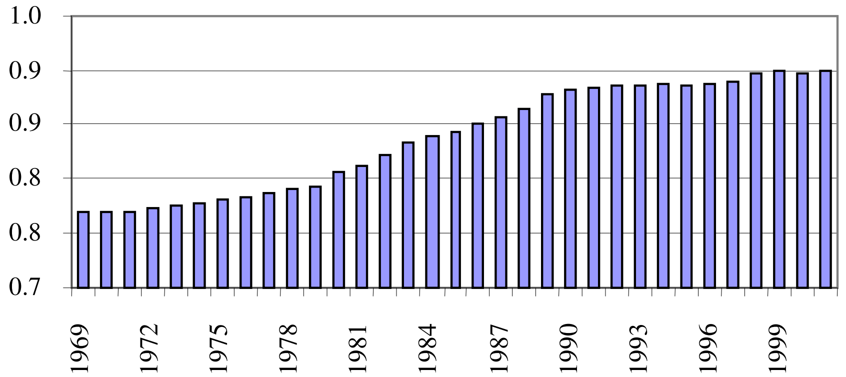
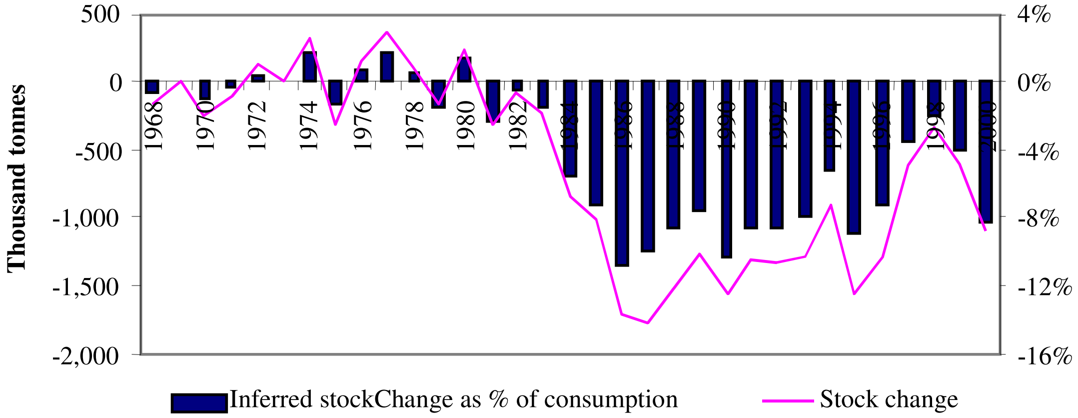


Figure 3.14 Inferred conversion rate for crude steel to be converted into steel



*Blue series scaled to the right hand axis. Consumption here means the domestic demand of crude steel, which is import plus production minus export

Figure 3.15 Crude steel stock changes

3.4.5 Iron and steel products

Production, import and export: Pig iron and crude steel are really ‘works in process’ (WIP) that have to go through final processes in the mills and foundries. There they are turned into final steel and iron products for delivery to downstream fabrication and manufacturing. Figure 3.16 displays the annual imports, exports and production.

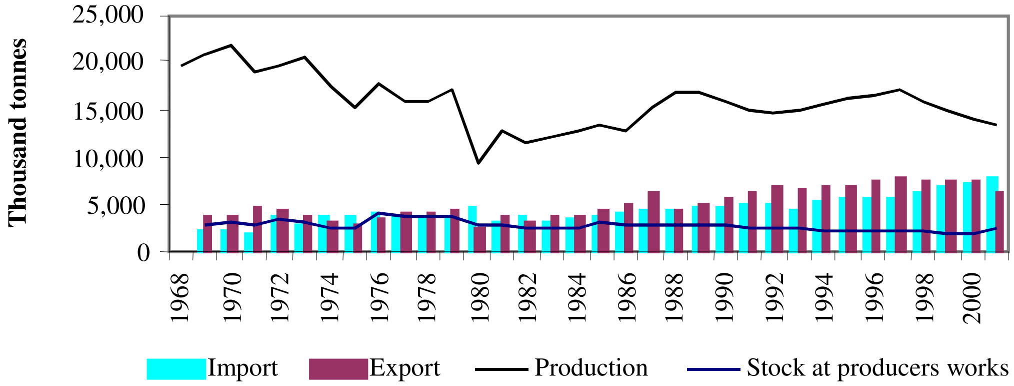


Figure 3.16 Steel products import, export, production and recorded producers' stock trend

The production series, however, is not the real yearly output of steel products; it is the delivery from the steel producers, which is used as an equivalent to the production because it is very difficult to compile production data without double counting. For example, cold rolled sheet production will be counted as output from the rolling plants. However, cold rolled sheet can be further processed into tinplate or coated sheets. Those further processed cold rolled sheets will then be counted as output from tinplate and coated sheet plants. Adding those two outputs together will lead to double counting.

A steep drop in 1980, due to the national steel strike, and a slow recovery thereafter followed a continuous decline in total production by UK iron and steel producers. The recovery was probably mainly due to a steady increase in exports since 1980. For the last 10 years total production has fluctuated around 16 Mt per year. Steel product production in the UK saw a surge in the late 1980s, tying in with an economic boom that occurred in the country at that time. The production however showed a declining trend again from 17.2 Mt in 1997 to 13.5 Mt in 2001.

Compared with crude steel and pig iron, there has been much more trade in steel products. For the last decade, exports fluctuated around 8 Mt per year, and imports at 7 Mt. There is an increasing trend in the imports since 1993. In 2001, the country imported 7.1 and exported 6.1 Mt of steel products.

Stock changes: In Figure 3.17, stocks of steel product held at producers' works are shown as the blue line. The producers' stock was about 2-4 Mt a year and the amount of this stock holding demonstrates a declining trend. If defining producers' stock level as the amount of stock divided by production at the producers' works, this stock level showed an increase between 1968 and 1980, which saw the highest producers' stock level at 30% of production due to the strike. The stock level declined gradually thereafter. In 2001, the producers held 2.4 Mt of stock, accounting for 17% of production. The recorded stock in Figure 3.17 only displays the producers' steel production stock. There are also substantial stocks held by stockists, converters and other distributors. The stock changes of steel products in the country therefore have to be checked by using equation (1) in section 2.

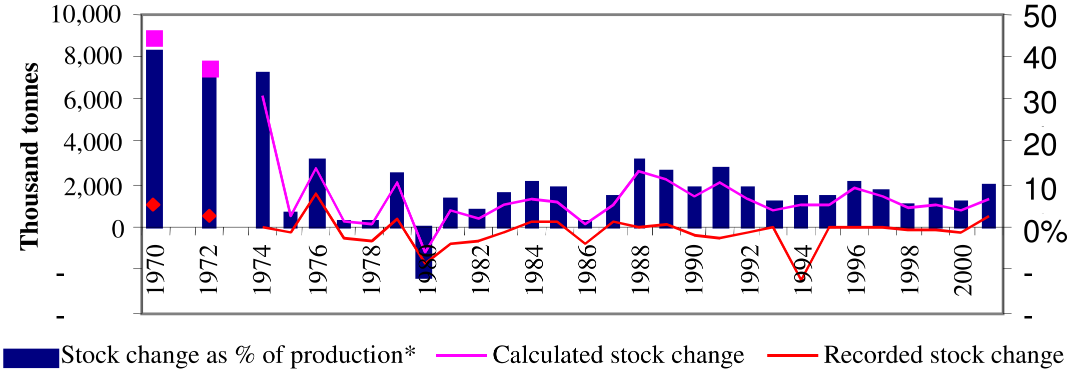


Figure 3.17 Steel products stock changes

3.4.6 New goods

Delivery from UK producers, import and export: Iron and steel products from the iron and steel sectors are the raw material input for the downstream fabrication and manufacturing, where they are used to build new goods such as cars, construction structures and household appliances. The iron and steel supply chain starts to become complicated at this points as there are numerous types of new goods completely or partially made from iron and steel products, resembling the "T" type material flow pattern (Macbeth and Ferguson, 1994).

The complexity of material flows in new goods fabrication and manufacturing leads to a simplified material flow account of iron and steel in new goods. It is assumed in this study that the deliveries of iron and steel to downstream new goods manufacturing sectors in a year are equivalent to the consumption of iron and steel in these sectors in that year. Consumption minus prompt scraps in a year gives the amount of iron and steel that flows out into the use phase in that year. Figure 3.18 illustrates the consumption of iron and steel in the nine manufacturing sectors covered by the project.

The construction sector consumes an average of around 3 Mt of iron and steel products per year, taking the largest portion. The vehicle sector consumes 2.4 Mt, and mechanical engineering 2.1 Mt on average yearly. Iron and steel consumption in cans and metal boxes, electric engineering as well as boilers, drums and vessels sectors consume less than 1 Mt. There is a dramatic decline of iron and steel consumption in the metal goods sector from 1.7 Mt per year to below 1 Mt. It seems there was a considerable decrease in iron and steel consumption in all the sectors around the 1981-1986 period.

Taking out prompt scrap (Table 3.2) from iron and steel consumed in the individual downstream manufacturing sectors, Figure 3.19 shows the total iron and steel contained in new goods produced in the UK that go to the use phase. Exports and imports of iron and steel contained in the new goods, using Table 3.3, are also illustrated. Both imports and exports demonstrate an increasing trend. There were more exports of iron and steel contained in new goods before 1980; however, imports have outstripped exports since 1981. Domestic production has supported more than 50% of the domestic demand, defined as domestic production plus imports minus exports, until 1995, after which imports increased and supported over 50% of domestic demand. The domestic demand has also been assumed as the total iron and steel contained in goods entering use in the EOL modelling in later sections.

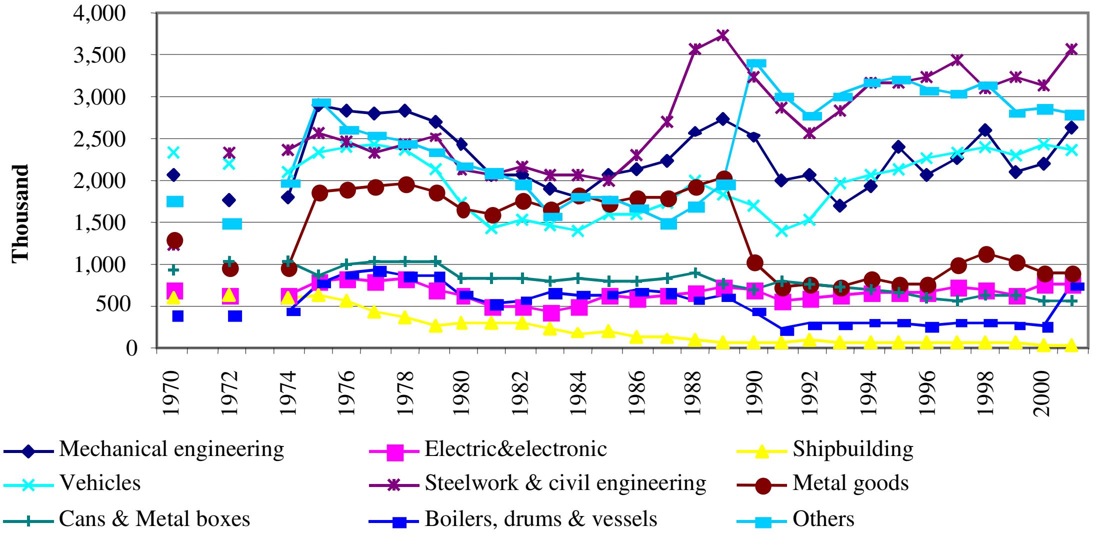


Figure 3.18 Iron and steel product deliveries to UK manufacturing and fabrication

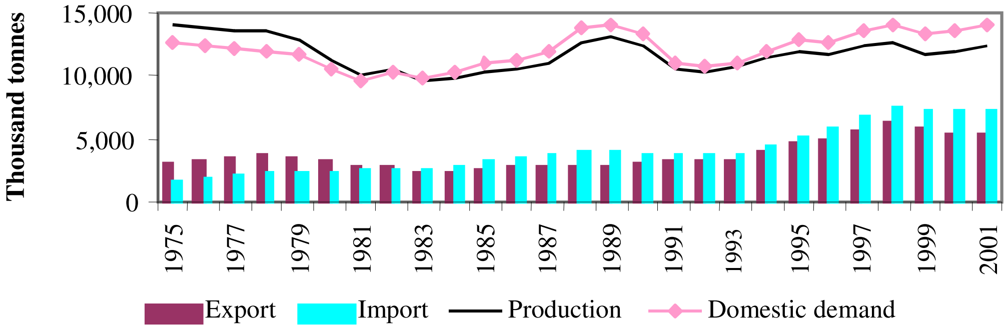


Figure 3.19 Production, demand and trade of iron and steel in goods

Stock changes: It is a demanding task to record the stock of new goods in mass. There are only some records of industrial and commercial stocks of new goods held by manufacturers and distributors, in economic rather than material terms. It is difficult to collect data on all of the stock of iron and steel contained in new goods. Inferring stock change in new goods fabrication and manufacturing is possible only when the stock level of new goods and the content of iron and steel in these stocks are known.

3.4.7 Overview of the iron and steel supply chain

While the previous sections looked into the material flows of the individual material categories, this section will examine their interaction along the supply chain. Figure 3.20 shows the demand flow, which is the production plus import minus exports, of four material categories. From a supply chain perspective, a demand flow of an upstream material is also the supply flow to satisfy a downstream demand flow.

In Figure 3.20, the demand flow of crude steel has the highest value over the years, followed by steel products; iron and steel in new goods; and scrap. The demand for crude steel was about 20 Mt per year between 1968 and 1980, after which demand dropped steeply to a level of about 15-16 Mt per year. There has been further decline since 1997. In 2001, the total UK crude steel demand was about 13 Mt.

Similarly, the demand flow for steel products was around 17 Mt per year until 1980, and then dropped to around 14 Mt. There was no overall upward or downward trend in steel product demand since 1980 despite a small peak between 1988 and 1990. Compared to crude steel, steel products showed a smoother demand trend. In addition, the difference between the two flows shows stock accumulation due to the imbalance between supply and demand: crude steel supply exceeded demand for steel products. This difference was bigger between 1968 and 1979, at approximately 5 Mt, than between 1980 and 2001, at approximately 2 Mt. This means that the steel industry improved its performance in managing its material and inventories to meet the demand in its downstream market. This improvement was probably due both to better material yield rates and to inventory management as a result of technological advances in material transformation and supply chain management (i.e. lean/JIT practices, partnership purchasing). The big dip of both crude steel and steel products in 1980 reflected the impact of the steel strike.

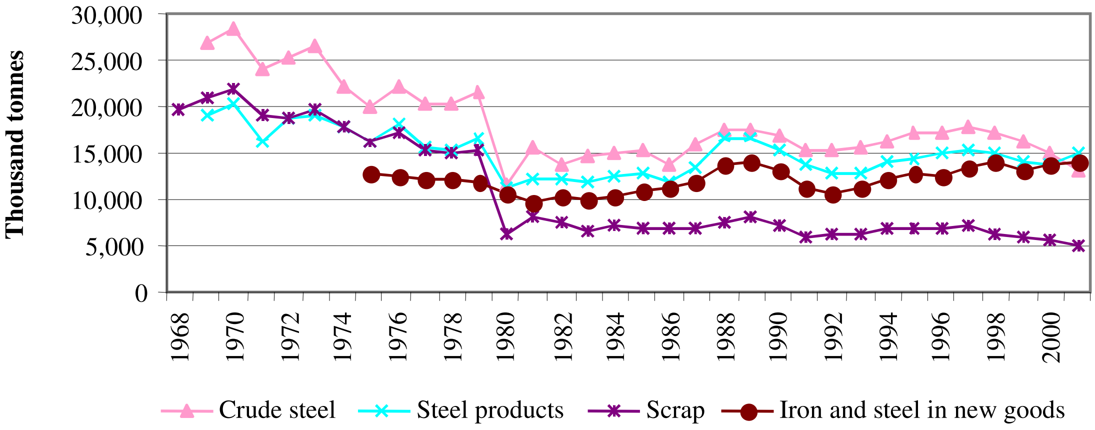


Figure 3.20 UK demand for iron and steel material categories

The demand flow of iron and steel in new goods fluctuated around 12-13 Mt per year between 1975 and 2001, with no overall upward or downward trend. This indicates that the final demand from the consumer was fairly constant over that period. Compared to crude steel and steel products, the demand flow of iron and steel in new goods is more even. Similarly, the industries showed improvement in balancing the supply of steel products to meet the needs of downstream new goods from consumers. Between 1975 and 1980, the difference between supply of steel products and demand of iron and steel in new goods was of order 3 Mt, subsequently reduced to around 2 Mt per year. On average, this difference was around 10-30% of the demand flow of iron and steel in new goods over the years.

The demand flow of iron and steel contained in new goods is the demand reflecting the needs of consumers and therefore the ultimate demand that drives supply of all the upstream iron and steel material categories. When looking at the above three flows together as a sub-supply chain, the crude steel supply is ultimately driven by the demand of iron and steel in new goods, while the steel products were the works-in-process (WIP). The difference between the flows of crude steel and iron and steel in new goods was about 7 Mt per year during 1975-1979, and 5 Mt per year after 1980, amounting to 30-50% of the flow of the iron and steel in new goods. This demonstrates the theory of systems dynamics by Forrest (1961), where downstream demand is distorted (i.e. amplified) in the upstream processes. The further upstream a process is positioned in a supply chain, the more distorted the final demand will be.

Reasons for this large difference include long manufacturing lead times, complicated distribution networks, and demand variability. A survey carried out by a supply chain group in the Cardiff Business School for the British metal industry in 2000 indicated that lack of knowledge of real demand; poor demand forecasting and planning; and adverse relationships and poor communications between supply chain partners contributed to high level of stocks (Taylor *et al.*, 2001).

Demand flow of the iron and steel in new goods is the final flow that decides the EOL iron and steel scrap arisings. The scrap demand flow in Figure 3.20, which is the consumption of scrap including home, prompt and EOL scrap in iron and steel works, shows a declining trend, falling from 15-19 Mt per year in the 1970s, to 5-7 Mt per year after 1980. This drop is partially caused by changes in the statistics, as they no longer include scrap consumed by iron foundries after 1980. This scrap consumption has been between 2 and 3 Mt per year. Even if scrap consumption in foundries were added to the total scrap consumption, the scrap demand flow would still decline. This means the UK capacity to process scrap is decreasing, and increasingly depends on other countries to close its iron and steel cycle.

3.5 Iron and steel scrap arisings

3.5.1 End-of-life scrap arisings and recycling rates

Estimates of EOL scrap arisings have been modelled using the methodology developed in Section 2.4. The model can be expanded as in Figure 3.21 to include prompt scrap and trade. The flow of iron and steel industry products into UK manufacturing industry is divided into nine different sectors. Part of the deliveries is turned into prompt scrap during manufacturing and fabrication of goods according to the prompt scrap rate of each sector (Table 3.2). The remaining iron and steel is incorporated into goods and then either exported or delivered to use in the UK together with imported goods.

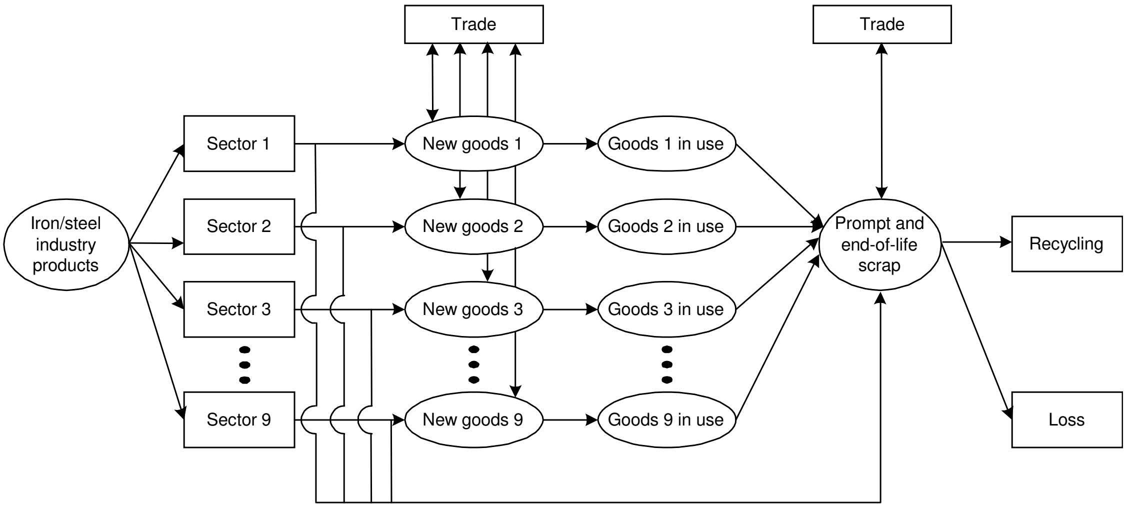


Figure 3.21 Modelling methodology to estimate prompt and EOL iron and steel scrap generation

The resulting flow of iron and steel contained in goods entering use in the UK is shown in Figure 3.22. The goods stay in use until they have reached the end of their service lives, according to the life span distribution of each category of goods. Table 3.4 gives information on the life spans that have been collected and used in the analysis to model iron and steel EOL scrap arisings.

One of the aims of this analysis was to compare the arisings of UK prompt and EOL scrap with the actual recorded prompt and EOL scrap recovered for recycling in the UK, in order to investigate the level of closure of the iron and steel cycle. Multiplying the iron and steel products input to UK fabrication and manufacturing with prompt scrap rates have derived the prompt scrap generation. The EOL scrap arisings have been modelled using three different lifespan distributions for each goods sector.

The derived prompt and EOL scrap arisings in 2001, using each of the different distributions, are shown in Figure 3.23. The figure shows that there are very small differences between the modelled arisings using the three distributions. This is because the inflow of iron and steel in the form of new goods into use has been relatively stable over the years. If there had been more significant upward or downward trends in the inflow of new goods into use, changing the distribution of product lifetime would have shown greater differences in the EOL scrap arisings. Using a distribution when the historical inflow of goods is not smooth but fluctuating smoothes out the irregularities in the inflow data, providing a better estimate of the EOL arisings. Figure 3.23 also shows the actual recycling of prompt and EOL scrap that has been generated within the UK (scrap consumption minus scrap imports plus scrap exports) in 2001.

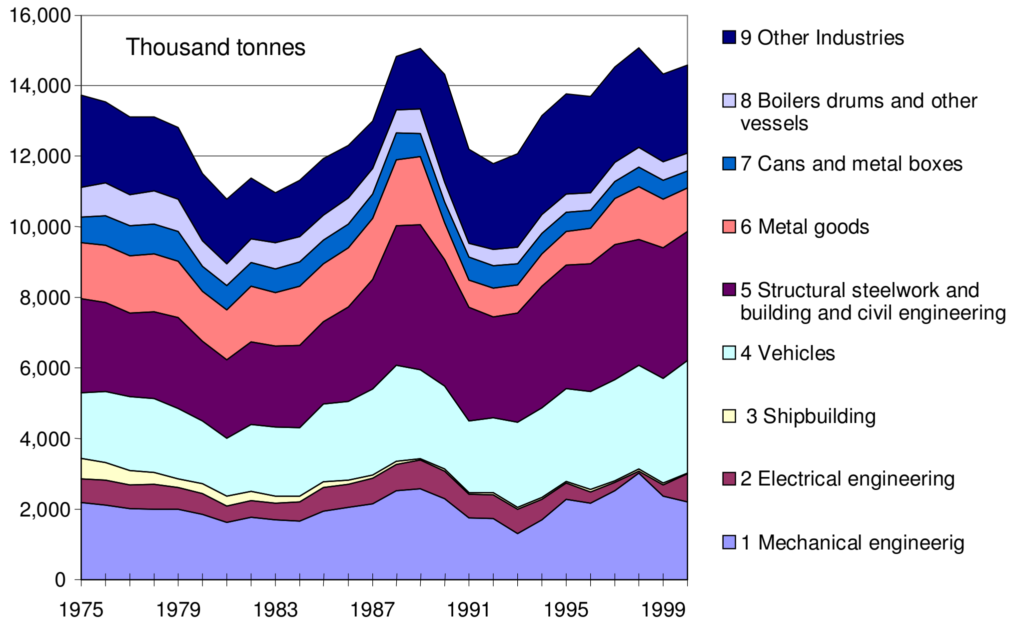


Figure 3.22 Iron and steel in finished goods going into use, 1975-2000

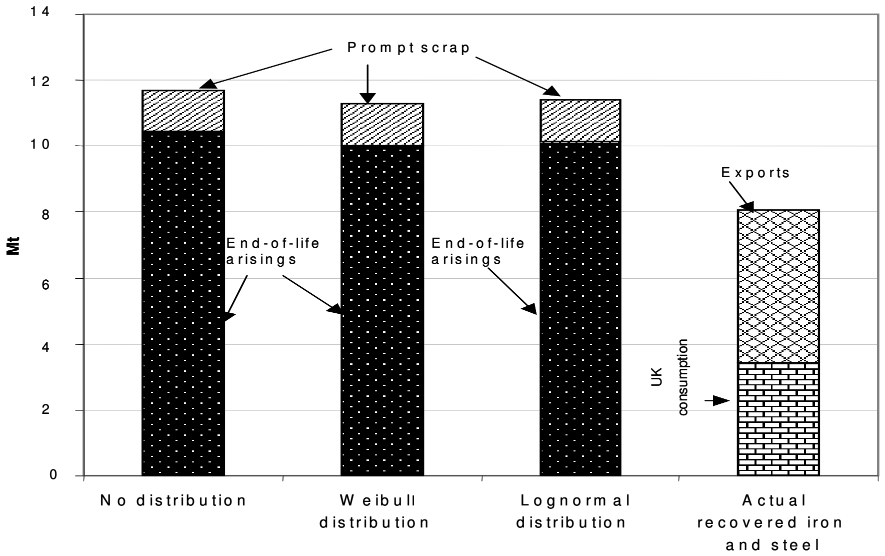


Figure 3.23 Modelled scrap arisings compared to actual scrap recycling

By comparing the modelled arisings with actual recycling, a recycling rate can be derived according to equation (3) in Section 2.4. This inferred recycling rate is given in Table 3.5 for each lifespan distribution. It appears that the inferred amount of scrap available is about three to four Mt more than the amount of scrap actually recycled. In other words, the inferred recycling rate in 2001 is 69-72%. The model thereby suggests that there is a significant amount of scrap that is not being recovered and recycled at present.

Table 3.4 Life span data used in modelling iron and steel end-of-life scrap arisings

Goods category	Average Lifespan [years]	Min and max Lifespan [years]	Source
Mechanical engineering	15	10-20	Kakudate *et al.* (2000); Michaelis (2000); Melo (1999);Hayashi (2000)
Electrical engineering	16	10-25	Elshkaki *et al.* (2002);Michaelis (2000); Simon *et al.* (2001); Melo (1999);Hayashi (2000)
Shipbuilding	60	-	Melo (1999)
Vehicles	13	1-16	Graedel *et al.* (2002);Melo (1999); SMMT (2001); Hayashi (2000); Michealis (2000)
Structural steelwork and building and civil engineering	60	20-100	Howard (1999); Graedel *et al.* (2002); van der Voet (2002); Fletcher (2001); Amato (1996)
Metal goods	13	5-15	Melo (1999); Michaelis (2000)
Cans and metal boxes	1	-	Melo (1999); Hayashi (2000)
Boilers, drums and other vessels	10	-	Michaelis (2000)
Other industries	25	-	Michaelis (2000)

Using statistics from Defra and the Environment Agency on how much waste was sent to landfill in 2000/2001, combined with information on how much of this waste is ferrous metal (see Appendix 3.3), it is derived that industrial and commercial waste together with the municipal waste make up about 2 Mt of ferrous metal going to landfill. This amount would explain a significant part of the 3-4 Mt of iron and steel scrap that is not being recovered at present.

Table 3.5 Inferred iron and steel recycling rates (2001), different distributions

Distribution	No distribution	Weibull distribution	Lognormal distribution
Estimated arisings (Mt)	11.7	11.3	11.4
Actual recycled amount (Mt)	8.1	8.1	8.1
Inferred recycling rate [%]	69	72	71

3.5.2 Sensitivity analysis of inferred recycling rate

The EOL scrap arisings estimated in this model are affected by the key parameters of average expected lifespans, prompt scrap rates and iron and steel contents of traded goods. To understand the reliability of the inferred recycling rate, the influence of these parameters on the predicted amounts of released scrap and thereby on the inferred recycling rate has been examined.

Estimates of the iron and steel content are only applied to traded goods in the model and changing these parameters radically does not have a significant effect on the predicated amounts of released scrap. The reason for the low impact of changing the iron and steel content is that imports and exports of goods have been largely similar in quantity and growth rate over the last 30 years, as can be seen in Figure 3.24, so that they largely balance each other out.

Decreasing all lifespans by 50% gives an increase in released end-of-life scrap in 2001 and thereby reduces the inferred recovery rate (Table 3.6). Using a Weibull distribution for inferring the end-of-life scrap arisings results in a reduction in the recycling rate to 63% from the original 72%. As the data are collected from 1975 to 2000, it is not possible to analyse what the effect would be of increasing the life spans by 50%. Again using the Weibull distribution, and changing all prompt scrap rates to 40% also reduces the inferred recycling rate to 63%. Decreasing all prompt scrap rates to 0%, and again using the Weibull distribution, increases the recovery rate to 74% from the original 72%.

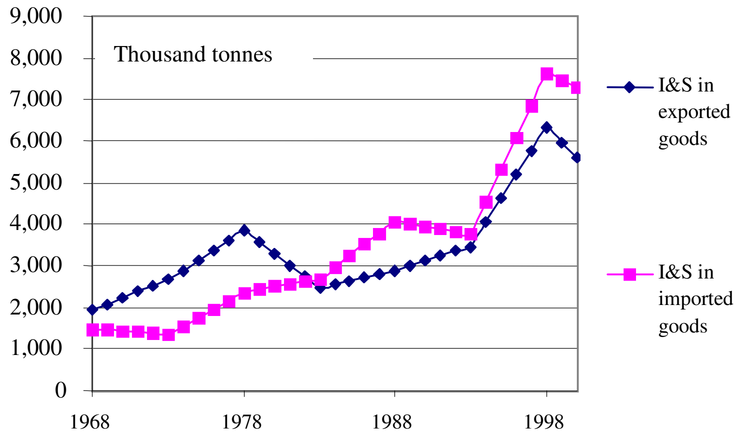


Figure 3.24 Trade of iron and steel contained in goods

Combining a reduction of the life spans by 50% and increasing all prompt scrap rates to 40% yields an inferred recovery rate of 58%. All these changes in life spans and prompt scrap rates result in a range of inferred recycling rates from 58 to 74% and do not fall far from the inferred recovery rate using the original life spans and prompt scrap rates (69 to 72%).

Table 3.6 Effect on inferred recycling rate (Weibull distribution) of changing prompt scrap rates and lifespans

Change of parameters	Inferred recycling rate [%]
Decrease prompt scrap rates to 0%	74
Increase prompt scrap rates to 40%	63
Decrease lifespans by 50%	63
Increase prompt scrap to 40% and decrease lifespans by 50%	58
With consideration of manufacturing and commercial stock	70

Apart from the possible effects of key parameters on the scrap arisings as analysed above, another factor is the industrial and commercial stock changes. In the model, it is assumed that the amount of iron and steel products delivered to end-users is equal to deliveries to downstream fabrication and manufacturing processes minus prompt scrap. In reality, however, there are considerable stocks stored by the manufacturers, assemblers, distributors and retailers along the supply chain to buffer market uncertainties.

There were more manufacturing and commercial stocks in the past than in the 1990s due to the rapid progress made in manufacturing technology, logistics, information and communication technology. The stock held by manufacturers and distributors is about 10-30% of the costs of goods sold in value annually (Lamming, 1996). The DTI latest survey in the manufacturing industry revealed the average stock level of an average manufacturer is about 12% of its cost of goods sold annually in 2002 (DTI, 2002). The method used to calculate the recycling rate by considering the stock issue is explained in Appendix 3.4. Using the data derived by considering the stock of iron and steel, the recycling rate inferred based on the Weibull lifespan distribution is 70% as shown in Table 3.6, which is again close to the original modelled result.

3.5.3 Sectoral recycling scenarios

The total arisings of prompt and EOL scrap arisings in the UK are estimated using the model outlined in Figure 3.21. By applying recycling rates to each of the modelled outflows of end-of-life scrap arisings and comparing the sum of the resulting flows to the actual recycling of scrap in the UK, the results can be validated. However, recycling rates for each goods sector are not readily available; if recycling rates are available it is not always clear how they have been derived (which is one of the main reasons for performing this study in the first place). Nevertheless, possible scenarios of recycling using the information available have been created.

A recycling rate of 89% was obtained from Defra for ‘metal products in industrial and commercial sector in the UK’, and this rate was assumed for ‘mechanical engineering’ and ‘other industries’. For ‘constructional steelworks *etc.*’, ‘vehicles’ and ‘Cans and metal boxes’, information from independent studies to determine their recycling rates has been obtained. It has been assumed that ‘Boilers etc.’ has the same recycling rate as ‘cans and metal boxes'. The recycling rates used and their sources are shown in Table 3.7. Information on recycling rates for the remaining sectors has not been found, and rates for these have been chosen to obtain a total scrap recycling rate that matches the documented scrap recycling in 2001.

Table 3.7 Literature based recycling rates for UK iron and steel goods

Goods category	Recycling rate [%]	*Source*
Mechanical engineering	89	Defra (2000)
Vehicles	87	ACORD (2001)
Structural steelwork and building and civil engineering	85	Ley *et al.* (2002)
Cans and metal boxes	37	May (2003)
Boilers, drums and other vessels	37	May (2003)
Other industries	89	Defra (2000)
Prompt scrap	100	Hunt (2003)

The scenarios are shown in Table 3.8. In scenario 1, the rate 0% is chosen for all sectors other than those in Table 3.6. This generates almost the same amount of scrap that was recycled in 2001: 8.03 Mt compared to 8.06 Mt that is the documented recovery of scrap in 2001. It is however likely that some scrap is recycled from electrical engineering and metal goods, so in scenarios 2 and 3 these sectors have recycling rates of 10 and 20%. The recycling rates of mechanical engineering goods and other industries have then been reduced slightly to obtain a recycled amount equivalent to that in 2001.

Providing the literature recycling rates are defined according to equation (3) and that they are realistic, the model suggest the largest scrap losses originate from the metal goods category and from electrical and mechanical engineering, which together make up more than 50% of the potential scrap loss (i.e. 50% out of the potential 3-4 Mt currently not being recycled). These would be products like domestic appliances, hand tools, cutlery, metal furniture, etc: products that are likely to be very dispersed in society and therefore difficult to recover for recycling.

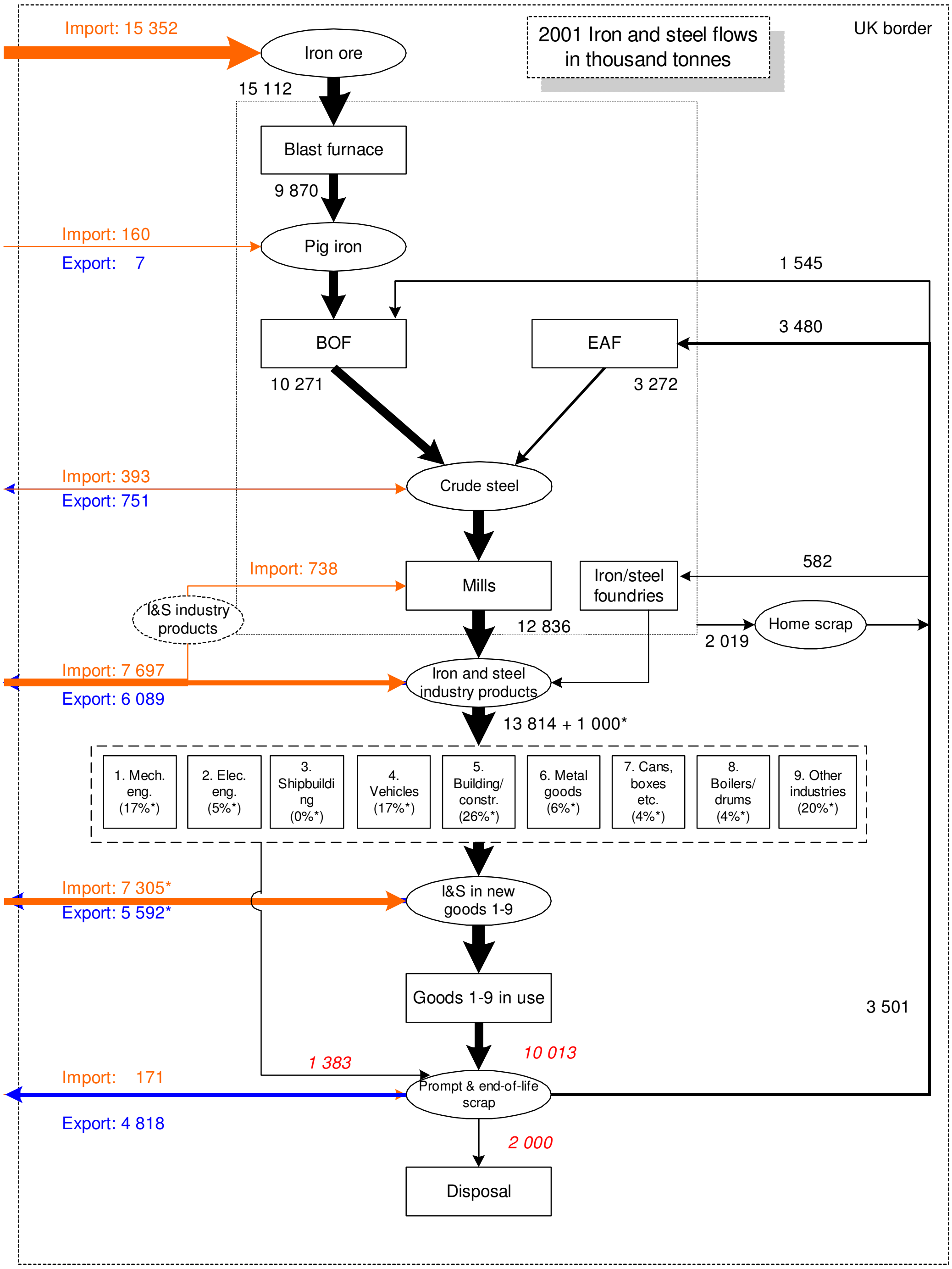
Table 3.8 Sectoral recycling scenarios

Goods category	2001 scrap arisings [Mt]	Recycling rates Scenario 1 [%]	Recycling rates Scenario 2 [%]	Recycling rates Scenario 3 [%]
Mechanical engineering	2002	89	80	79
Electrical engineering	627	0	10	20
Shipbuilding	5	0	0	0
Vehicles	2340	87	87	87
Structural steelwork and building and civil engineering	1070	85	85	85
Metal goods	1234	0	10	20
Cans and metal boxes	392	37	37	37
Boilers, drums and other vessels	596	37	37	37
Other industries	1747	89	89	80
Prompt scrap	1383	100	100	100
Inferred amount of recycled scrap [Mt]		8.03	8.04	8.06

3.6 Summary of current iron and steel flows

The previous sections have explained how data have been compiled for the flows of iron and steel in the UK reaching back several decades. All data compiled are available in Appendix 3.5 at the end of the report. Figure 3.25 shows an overview of all the flows of iron and steel for the year 2001. The following text summarises the flows in this year, using the compiled data together with necessary modelling and assumptions as reported in the previous sections.

All iron ore used in iron and steel production in 2001 was imported, as there is no longer any mining of iron ore in the UK. Most of the pig iron used in production is produced domestically; only a very small part is imported. In 2001, about 75% of UK produced crude steel came from integrated steelworks (BF/BOFs) and 25% from electric arc furnaces (EAFs). Further down the chain it appears that almost half of the iron and steel products produced in the UK are exported and that imports of iron and steel products are just as high as the exports. This implies that a large part of the domestically produced iron and steel products is different from those required by UK goods manufacturers and fabricators, or that it is financially more attractive for UK iron and steel producers to export and goods manufacturers to import iron and steel products.



*Iron foundry products

Note: flows may not balance each other in this chart due to industrial and manufacturing stocks held businesses which are not included here.

Figure 3.25 System overview of UK iron and steel flows in 2001

About 15 Mt of iron and steel products were delivered to UK goods manufacturers and fabricators in 2001. Most of this iron and steel went into building and construction followed by other industries, mechanical engineering and vehicles. These four sectors currently consume 80% of the total deliveries of iron and steel products in the UK. Just less than 10% of the total iron and steel deliveries to UK manufacturers was turned into prompt scrap and recycled back into the system. Out of the iron and steel in goods produced in the UK about 40% was exported, and the rest was delivered to use in the UK. There is a substantial amount of iron and steel in goods imported to the UK: in 2001 more than 7 Mt of iron and steel in goods were imported.

About 10 Mt of end-of-life scrap were released in 2001. Together with available prompt scrap arisings this makes up more than 11 Mt. 4.8 Mt of this scrap were exported and recycled abroad whereas 3.5 Mt were recovered and recycled domestically. A further 2 Mt ended up in landfill. The recovery of iron and steel scrap arisings in the UK thereby seems to be working relatively well in that about 70% of the scrap arisings is being recovered and recycled (although not domestically). However, the flow diagram suggests there is still room for improving recovery and recycling practices of iron and steel in the UK.

4 ALUMINIUM MATERIAL FLOW ANALYSIS

4.1 Introduction

Aluminium is the third most abundant element after oxygen and silicon, accounting for 8% of the earth's crust. In this section, the supply chain systems for aluminium in the UK will be explained. Material categories and transformation processes will be elaborated and the material flows will be examined.

4.2 System description

The system model for aluminium is shown in Figure 4.1. Today in the UK, the aluminium story begins at the primary smelter stage as all of the alumina used is imported. Although there was alumina production from bauxite in the UK before 2000, none of the alumina produced was put into primary aluminium production.

4.2.1 Material categories

Bauxite: The aluminium ore most commonly used for the extraction process is bauxite, which is impure since it contains appreciable amounts of iron compounds. Naturally occurring aluminium compounds, known as alumino-silicates, are very stable and the extraction of metallic aluminium is a very complex series of industrial processes. All the bauxite used in producing alumina in the UK before 2000 was imported.

Aluminium prompt and end-of-life scrap: The contribution of secondary aluminium production to the total unwrought aluminium (ingot, slabs and billets) production of the UK is illustrated in Figure 4.2, which shows that the share of secondary aluminium to overall unwrought aluminium production in the UK has declined. This is because there has been a dramatic increase in the production of primary aluminium.

The aluminium industry usually only differentiates between two types of scrap: new and old scrap. New scrap is a combination of home and prompt scrap.[11] Much prompt industrial scrap is similar in principle to internal scrap from the semi-fabrication stage. It may be off-cuts of sheet and extrusions, or damaged products, which are easily identifiable by type of alloy and are relatively uncontaminated. Most prompt scrap, together with the scrap from semi-fabricators that do not have their own remelting facilities, is suitable for returning to semi-fabricators or to specialist remelting operations. A toll conversion practice is common for this type of scrap, where the semi-fabricators (rolling mills or extruders) toll-convert scrap from the customers back into billets or slabs and then into new extrusions or rolled products for payment of a conversion fee.

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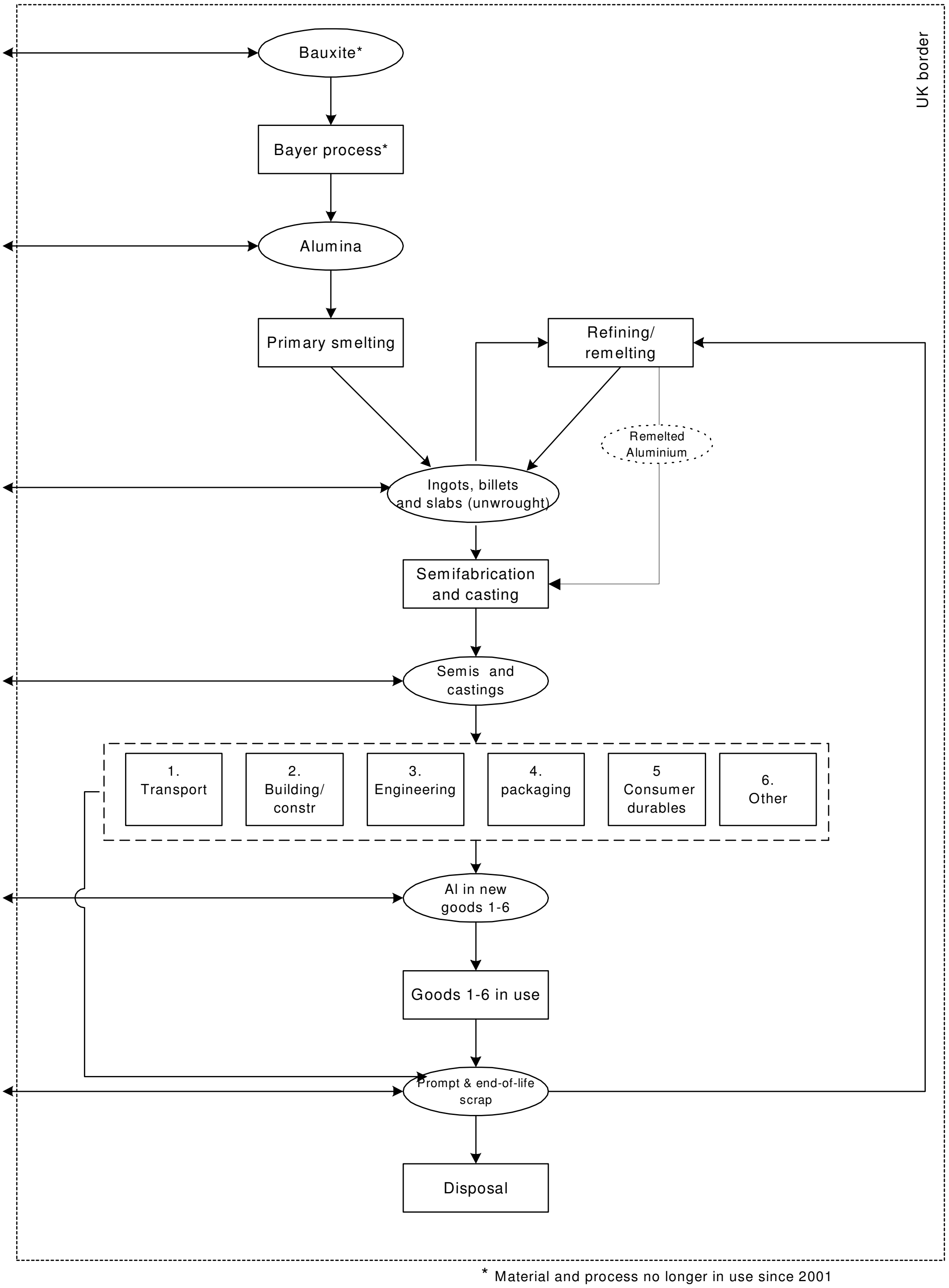
[11] Home scraps are cuttings, turnings, salt slag and dross from aluminium production, and constitute a large part of the total scrap consumed within the UK. Prompt scrap is generated at manufacturing sites that produce new goods containing aluminium (see Section 2).

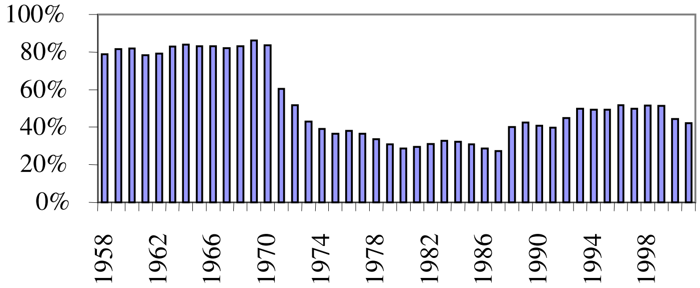


Note: No alumina produced in the UK in recent years has been used for the production of primary aluminium. Instead it has been used for refractory, abrasives etc.

Figure 4.1 System overview of aluminium flows in the UK

Other forms of new industrial scrap are machine turnings, swarf and other material from the milling, boring, or cutting of metals. This scrap may be of mixed alloy composition and will almost certainly be contaminated with oils, other metals, paint, dirt, etc. It is normally collected by merchants or supplied directly to secondary smelters for processing (King, 2001).

EOL or old scrap denotes scrap that arises when goods become obsolete after use. There are many recycling facilities in the UK, operated by several different companies.



Data source: A*nnual report* (2003) from Alfed and previous issues; *World Metal Statistics* (2002) and previous issues from WBMS.

Figure 4.2 Remelt aluminium as share of total unwrought aluminium production

Alumina: Bauxite is turned into alumina (Al_2O_3) in the well-established Bayer process. 100 tonnes of bauxite produces about 40-50 tonnes of alumina. Normally this process is carried out close to the mine site, but there are plants in Europe where the alumina is produced at the aluminium smelter site.

Ingots, billets and slabs (unwrought aluminium): Aluminium ingots, billets and slabs can be produced either by the electrolytic reduction of alumina or by secondary smelters. Molten unwrought aluminium can be cast into ingots or larger blocks known as sows which are destined for remelting. More usually the molten aluminium from the electrolytic cells is transferred to a holding furnace typically with a capacity of up to 50 tonnes of metal. There it is alloyed with a variety of elements such as iron, silicon, magnesium and copper. The alloy is then cast into extrusion billets or rolling slabs using a semi-continuous process known as direct chill (DC) casting. These products can be sent directly to the casting houses and wrought processing factories for fabrication into semi-finished products, such as extrusion and sheet, plate and foil. Almost all UK produced primary aluminium is cast into slabs or billets. Aluminium ingots, billets and slabs are intermediate products, which need to undergo further operations to make them wrought products.

Semi-fabrications and castings: Semis and castings consist of all the finished aluminium that leaves the aluminium producers in the form of alloys, castings, rolled products, extrusions, powders, etc. Aluminium and its alloys are generally divided into two broad classes: castings and wrought (mechanically worked) products. Wrought aluminium and its alloys are specified into nine series of European Standards and are classified by chemical composition in an internationally agreed four digit system (Alfed, 2002). Typical wrought products are extruded products such as bars, sections and tubes, rolled products such as plates, sheets, strips and circles, and wires. Wrought and cast products can be processed from primary unwrought aluminium. They can also be produced from recycled scraps directly.

Despite good statistics on the production of different aluminium fabrications and castings categories, care must still be taken to avoid double counting. For example, both aluminium extrusion and forgings are semi-fabrications, but forgings are sometimes produced from extruded bars. If the metal is counted in the supply chain as an aluminium extrusion it should not then be counted again as an aluminium forging.

New goods: New goods are all the physical products that are manufactured/fabricated to be used in the economy by their private, corporate or governmental consumers. They typically contain a variety of components made of various pure and composite materials. The category of *aluminium contained in new goods* accounts only for the aluminium that is embodied in all the different new goods that are about to enter the use phase in the UK or abroad.

4.2.2 Processes

Production

In the UK, there are two routes for aluminium production: primary production, where alumina is used as the main raw material; and secondary production, where aluminium scrap is used as a source of aluminium. Bauxite mining and production of alumina take place outside the UK. There are three primary smelters in the UK. The Alcan smelter in Lynemouth and the smelter owned by Rio Tinto and Kaiser Aluminium in Anglesey are the two largest, with an annual production of about 140 kilotonnes (kt) of primary aluminium. The production plant in Fort William is owned by British Alcan and has a production of around 40 kt per year. There was a fourth plant in Scotland at Kinlochleven but it closed in 2000 and its hydropower supply is now being redirected to the plant in Fort William.

In the primary production route, aluminium is produced by the electrolytic reduction of alumina. On average it takes some 15.7 kWh of electricity to produce one kilogram of aluminium from alumina.[12] The alumina is dissolved in a molten bath of mainly cryolite (Na_3AlF_6) at a temperature of approximately 900 ºC. Fluorides are added to lower the operating temperature. The electrolytic cell comprises a carbon cathode, insulated by refractory bricks inside a rectangular steel shell, and a carbon anode suspended from an electrically conductive anode beam. Liquid aluminium is deposited at the cathode at the bottom of the cell and oxygen combines with the carbon anode to form carbon dioxide. The anode is therefore consumed continuously during the process. The cathode is not

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[12] http://www.world-aluminium.org/production/smelting/index.html

consumed but deteriorates with time. It absorbs electrolyte, resulting in swelling and cracking, and needs to be replaced every 5-8 years. Molten aluminium is periodically withdrawn from the cells into crucibles. The crucibles are transported to the casting plant and the aluminium emptied into heated holding furnaces. Alloying is performed in these furnaces and the temperature is controlled to suit downstream casting operations.

Apart from adding alloying elements, the metal is also refined by removing impurities such as sodium, magnesium, calcium, oxide particles and hydrogen. This is done by injecting a gas such as argon, nitrogen and chlorine into the molten metal. Additions to refine the grade of the aluminium are also made. Titanium and titanium boride are the most common additives for this purpose. Skimmings (also called drosses) created on the surface by oxidation of the aluminium are raked off and recycled by remelting operators. When the desired composition of the aluminium is achieved, the molten metal is cast. Slabs, T-bars and billets are cast in vertical direct chill casting machines that have movable holding tables at the bottom of the mould. The table is lowered as the ingots are formed. These cast products can then be sent directly to the extrusion presses and rolling mills for fabrication into semi-fabricated products. Process scraps from semi-fabrication are collected for remelting, either as fines/chips or as compact scraps and are recycled back to the original material (EAA, 1996).

In the secondary routes, there is a range of furnaces used to melt the scrap. The type of furnace to be used is determined by the size, oxide content and the degree of contamination of the scrap and also by its pre-treatment. Pre-treatments of the scrap include de-coating and de-oiling if necessary, which improves the melting rate and reduces the potential for emissions and generation of skimmings. Scrap is sometimes sorted into alloy groups in order to produce the desired alloy with minimum reprocessing. Coreless induction furnaces are used to melt reasonably clean and finely divided aluminium grades. Rotary or reverberatory furnaces are used for melting a wider variety of scrap.

Fluxes such as fused salt, which is a mixture of sodium and potassium chlorides and some fluorides, are used during the melting process to prevent oxidation and to absorb impurities. Salt slag is tapped from rotary furnaces after the metal and recycled to recover any aluminium contained in the slag. Alloying elements may be added to the melt before it is tapped either directly into a casting system or into a holding furnace where further refining can be done. Following impurity removal, casting operations are generally performed in the same manner as in primary aluminium production.

The energy consumption of the secondary route is about 5% of that of primary route, one of the major advantages of the secondary route over the primary. This can be coupled with the ability of the aluminium alloys to be recycled without any loss of properties, in both open and closed loops, which make this material so suitable for recovery.

The secondary route in the UK comprises two types of producers: refiners and remelters (Figure 4.3). Refiners, also called secondary smelters, produce casting alloys and deoxidisation aluminium; remelters produce wrought alloys (OEA, 2002). In the UK, about 20% of the remelters' input into their furnaces is primary aluminium. Given that almost all UK produced primary aluminium is cast into slabs or billets, the remelters are mostly using imported primary ingots.

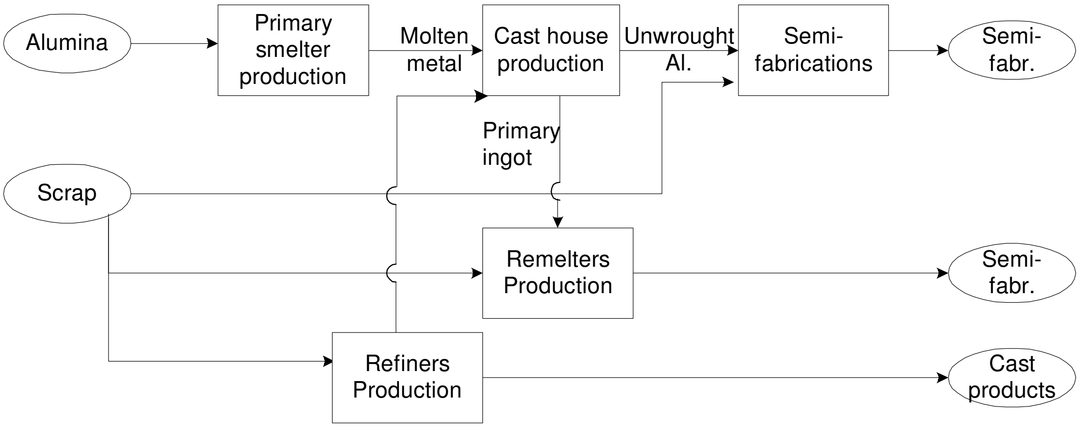

Figure 4.3 Secondary aluminium production routes

Fabrication and manufacturing

Aluminium castings and semi-fabrications such as extrusions, rolled products and forgings from the primary and secondary route have to be further processed in the downstream supply chain in order to be used in making new goods. To produce components ready for use in automobile manufacturing, subsequent process stages such as cutting, joining, forming or/and surface treatment are necessary. In supply chain terms, these are called raw material suppliers, or third tier suppliers. After these processes, the sections are sent to vehicle component manufacturers where components such as seat rails, bumpers, window frames and radius rods are produced for vehicle subassembly and assembly (King, 2001). These manufacturers are called component and subassembly suppliers, or second tier suppliers. The components and subassembly are then delivered to the next supply chain stage, first-tier suppliers or vehicle original equipment manufacturers, where aluminium components and subassemblies together with other components and subassemblies are assembled into vehicles. Similar supply chain structures exist for other types of new goods manufacturing.

The European Aluminium Association (EAA) has categorised new goods containing aluminium into nine main groups based on the industrial sectors they come from. Table 4.1 demonstrates the wide range of industrial sectors involved in the aluminium material flows and the complexity in tracing the aluminium flow through these sectors.

Apart from the tiered supply chain structure in different new goods fabrication and manufacturing stage, the distribution channels of aluminium semi-fabrications and castings have to be considered in a material flow study. Stockholders play an important role in distributing aluminium products flows within and outside the UK. In the early 1990s, up to 70% of the aluminium product market in the UK was handled by stockholders.[4] According to the London Metal Exchange (LME), the stocks from the registered warehouses rose from 100 kt in 1989 to 2.5 Mt in 1993. This stock, together with stock held at the aluminium producers, corresponded to about 90 days of aluminium delivery in 1993 (King, 2001).

Table 4.1 Classification of aluminium containing goods

	New goods categories	**Sub-categories**	**SIC Sectors**
1	Transport	Road transport Caravans and mobile homes Rail transport Aircraft and aerospace construction	34.1+ 34.2+ 34.3+ 35.1+ 35.2+ 35.5+ 35.4+ 35.5
2	General Engineering	Industrial machinery and accessories Industrial cocks, taps, pumps and couplings Liftings, transfer and handling equipment Precision engineering, medical apparatus instruments Mining and earth moving equipment Nuts, bolts, nails, building fixes	28.2+ 28.3+ 29.4+ 29.5+ 29.21+ 29.22+ 29.24+ 33.2+ 33.3+ 33.5
3	Electrical engineering	Power transmission and distribution Electrical machinery Telephones, communications and electronics Domestic/industrial equipment Atomic energy	31.1+31.2+ 31.3+ 31.5+32.2
4	Building and construction	Construction structures, scaffolding Building and construction roofing, exteriors cladding and accessories Doors, windows, curtain-walling Prefabricated houses and building Public works	28.11+ 28.12+ 28.63
5	Industrial refrigeration, chemical, food and agricultural	Industrial deep freezing and refrigeration Chemical industry Foods and drink industries Agriculture	24+ 29.23+ 29.3+ 29.71
6	Packaging	Impact extrusions for packaging uses Cans, can-end and lids Jar and bottle closure and caps Barrels, flasks and drums Foil for packaging Other packaging	28.72
7	Domestic and office equipment	Hollowware and kitchen utensils including camping Domestic machines and appliances Light fitting and equipment Office and school equipment and furniture	28.61+ 29.71+ 32.3+ 30.0+ 36.1
8	Powder and paste	Non-lamellar powder Paste	24.3+ 28.4+28.5
9	Miscellaneous	Iron and steel and other metallurgical uses Metal wares Arms and ammunition Others	27+29.6+ 36.2+ 36.3+ 36.4+ 36.6 + all others

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[4] *Aluminium Industry,* 1993, Vol 12 No. 3, p. 2.

Aluminium flows become further complicated when considering the interactions between different industrial sectors at the new goods stage, introducing further possibilities of double counting. The content of aluminium in new goods varies across different product categories and changes over time. Aluminium content for an average US-built automobile has risen from 51 kilograms in 1978 to 93.3 kilograms in 1997 (Roskill, 1999).

Use: New goods are manufactured to be sold to end customers, who purchase them for the services they provide. Many of the new goods manufactured in the UK are exported, and many of the new goods in use in the UK come from imports. It is therefore vital to account for trade in order to establish the quantity and quality of new goods entering use in the UK. The outflow of EOL products is a consequence of the limited use time of new goods. For this reason the characteristics of the use phase are very different from those of the other processes in production and manufacturing.

First, the material transformations of the use phase are usually unintentional and an effect of product use. Three types of transformations are relevant for the industrial ecology of materials in the use phase: physical alteration, contamination, and dissipation. Product use can of course result in a combination of these three transformations. Contamination of a material during use with other materials or substances (e.g. food on aluminium foil containers) raises the same issues as the fact that most final goods already contain many different substances (e.g. a vehicle contains steel, aluminium, copper, plastics etc.). Recycling activities need to separate the desired material from the others without unacceptable environmental impacts and within reasonable cost. During dissipative use goods are dissipated in the environment, with or without physical alteration, and cannot be collected after use for disposal or recycling (Ayres and Simonis, 1994). Dissipative uses of aluminium include the use of aluminium powder in the chemical industry, for fertilisers, paints, etc.

Second, unlike most other processes, use cannot be modelled as an instantaneous transformation of material from input stock into material, which is added to the stock of output. This time-dependent MFA, like many others, uses time increments of one year. The reason for this is simply that most data is collected on a yearly basis. This generally justifies the assumption that material that enters a transformation process in one time period as input is processed and leaves it as output in the same time period. Most goods containing aluminium, on the other hand, are used for several years, and the assumption of instantaneous transformation does not hold for the use phase. It is therefore more appropriate to model the use phase as a transformation process as well as a material stock of goods in use. As for the MFA of iron and steel, a time series analysis has been applied to the stock of aluminium in goods in use. Aluminium contained in the new goods that enter the use phase becomes available as EOL scrap only after the time delay of the goods' service life.

4.3 Data availability and sources

Most time series data on the upstream aluminium flows have in this study been collected from *Metallstatistik*, published by the German Metallgesellschaft, and *World Metal Statistics*, published by the UK-based World Bureau of Metal Statistics (WBMS). These two publications compile UK information provided by the Aluminium Federation (Alfed) and the European Aluminium Association (EAA) which collate information reported by UK producers. Relevant Customs and Excise trade statistics are given in *Metallstatistik* and *World Metal Statistics*. There is a lot of overlap between the data in the two publications. Most data for the aluminium system in this study have been collated for the years 1958 to 2001 from these two sources, which are treated as one and will be referred to as WBMS.

There is a small portion of data used in this study from Alfed annual statistics, which are available from 1978. There are some discrepancies between the WBMS and Alfed data for some of the material categories, described in more detail under the relevant sections. The general rule for reconciliation is that data from WBMS will be used for the early years for which Alfed statistics are not available.

Bauxite, alumina and unwrought aluminium: Both *Metallstatistik* and *World Metal Statistics* have time series data for these materials. Comparison between the sources indicates that both data are very similar, which verifies the reliability of both. WBMS bases its statistics on reports from Alfed, and this source is used for the upstream material categories.

Scrap: WBMS published statistics of scrap consumption in the secondary smelters in the UK, provided by Alfed, in the 1970s. However, this information was regarded as confidential after 1982 and has not been available since. Therefore, scrap consumption after this year has been estimated using yield rates. If it is shown that X tonnes of scrap produces Y tonnes of ingot, then the yield rate is calculated by (Y over X) times 100%. Supposing that this yield rate is 85%, this means that 100 tonnes of aluminium scrap will be needed to produce 85 tonnes of specification ingots. The 85% factor can then be used to calculate how much scrap must be available to produce the known tonnes of secondary ingots in the years after 1982.

Alfed publishes data on secondary ingot and wrought aluminium production predominantly from scrap in its annual statistics. The scrap consumed in the secondary ingot production can be inferred using the above yield rate. The scrap consumed in the wrought production has to be inferred differently. It is suggested that the total input consumed for the output from the wrought production (predominantly using recycled scrap from fabrication) equals the output multiplied by a factor of 1.03 (Askew, 2003, *pers. comm.*). Of the input, 20% is primary aluminium and the rest scrap.

Customs and Excise gathers data on aluminium scrap imports and exports, which are available from WBMS, although this does not differentiate between prompt and end-of-life scrap. The vast quantity of fabricators and manufacturers makes it virtually impossible to collect this data directly. There is in fact no institution in the UK that attempts to estimate this important information. Estimates of prompt and end-of-life scrap arisings in the UK have therefore been modelled in this study.

Aluminium semis and castings to manufacturing: Deliveries of aluminium to UK goods manufacturers come from UK producers, UK stockholders and imports. As mentioned earlier, it is estimated that up to 70% of the UK aluminium product market is handled by stockholders, making it difficult to generate data on the amount of aluminium that enters each industry sector. *Metallstatistik* contains data on deliveries to UK manufacturers and traders, dividing the deliveries into nine different sectors (Table 4.1). However, closer examination of the data reveal quantities of deliveries that appear too small to include all exports of aluminium containing goods. This is thought to be because some manufacturers have their own foundries and this aluminium input will not appear in the *Metallstatistik* data set. Another reason is that trade classification codes have changed over time, which have resulted in aluminium being categorised in the ‘wrong’ group with possible distortion of this data set.

Alfed also has statistics on the despatches of aluminium products to the downstream manufacturing sectors, but in a slightly different reporting format. The data is provided as despatches of aluminium castings, extrusions and rolled products from UK producers, and imports and exports of these products. The delivery of aluminium products to the downstream sectors can be inferred by adding the dispatches and imports and then subtracting the exports of the three categories of aluminium products. The proportion of aluminium going into each industry sector is then estimated using a percentage split provided by Alfed. The percentage split is given for each type of aluminium product, with different values for extrusions, rolled products and castings respectively. Data on dispatches of extrusions, rolled products and castings are available for 1978 to 2001, while imports and exports are available for the 1981-2001 period. The percentages divide the deliveries into six categories: *transport*, *construction*, *engineering*, *packaging*, *consumer durables* and *other*.

The deliveries recorded by the EAA split the aluminium into nine industry sectors (see Appendix 4.1 for more detail on the nine sectors). SIC codes have been assigned to these nine sectors (Table 4.1). There is no similar detailed information for the six categories reported by Alfed, but Table 4.2 shows the SIC codes that are believed to correspond to each of the six categories. It is assumed that the split between sectors is constant over the time period studied.

In order to model construction scrap arisings, the data provided by *Metallstatistik* have been used for the years 1958-1977. For packaging, data from the Aluminium Packaging Recycling Organisation (Alupro, 2003) have been used for the years 1999, 2000 and 2001 to receive a more accurate figure for this specific sector. When comparing the amount of aluminium entering packaging generated using the Alfed split with the Alupro figures, they are of the same order.

Table 4.2 New goods categories

	New goods categories	SIC Sectors
1	Transport	34.1+ 34.2+ 34.3+ 35.1+ 35.2+ 35.5+ 35.4+ 35.5
2	Construction	28.11+ 28.12+ 28.63
3	Engineering	28.2+ 28.3+ 29.4+ 29.5+ 29.21+ 29.22+ 29.24+ 33.2+ 33.3+33.5+31.1+31.2+ 31.3+ 31.5+32.2+24+ 29.23+ 29.3+ 29.71
4	Packaging	28.72
5	Consumer durables	28.61+ 29.71+ 32.3+ 30.0+ 36.1
6	Other	24.3+28.4+28.5+27+29.6+ 36.2+ 36.3+ 36.4+ 36.6 + all others

Depending on the manufacturing sector, different amounts of prompt scrap are generated from cutting, drawing, extruding or other shaping of the metal to produce the final goods. In the analysis the inflow of aluminium products to each sector has been multiplied with specific rates to generate the flow of prompt scrap from the fabrication and manufacturing stage. A prompt scrap rate of 5% has been used for all sectors apart from transport and packaging, for which prompt scrap rates of 20% and 10% have been used respectively (Askew, 2003, *pers. comm.*). These rates have been assumed to be constant over the time period analysed. The rates are shown in Table 4.3.

Table 4.3 Prompt scrap rates for UK manufacturing of goods containing aluminium.

Goods category	Prompt scrap rate [%]
Transport	20
Building and construction	5
Engineering	5
Packaging	10
Consumer durables	5
Other	5

New goods: To derive the aluminium content of traded final goods, all the goods that contain aluminium (Appendix 4.2) are selected and compiled into the six sub-categories of industry sectors. The total mass of each sector is then multiplied with estimated average aluminium content, shown in Table 4.4, based on industry experts' estimates (Askew, 2003, *pers. comm.*). Data for trade in new goods have been collected from HM Customs and Excise for every 5 years between 1968 and 2000. The data have then been linearly interpolated to yield yearly values and aggregated into the six industry sectors.

Table 4.4 Aluminium content of traded goods

Goods category	Aluminium content [%]
Transport	10
Building and construction	90
Engineering	5
Packaging*	100
Consumer durables	20
Other	10

* The aluminium content of packaging is not strictly 100% as some aluminium foil is used to produce laminates using paper or plastics. As no further data is available, 100% is used as an approximation.

4.4 Analysis of aluminium time series data

In this section, individual flows describing an individual material category will be analysed. Upstream production, import and export activities are eventually driven by the supply-demand mechanism in the downstream market. In order to show the relationship between domestic production and demand, the figure for *domestic demand* has to be derived. When data are available on the consumption of a material in its downstream process, these data are used as the *equivalent to demand*. When such consumption data are unavailable, domestic demand is derived by adding imports and production and subtracting exports.

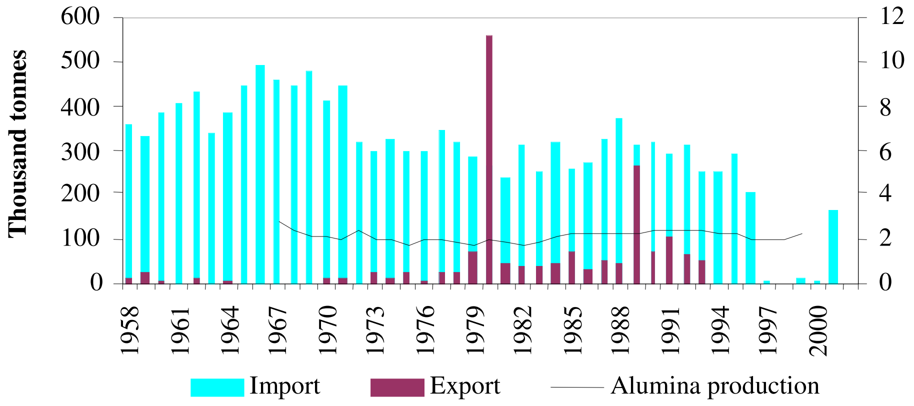
Stock changes within an individual material category will also be explored. The stock changes can be calculated if there are data for the total available material (including UK production and purchasing/imports) to a process and the actual consumption of the specified material in the downstream processes. Where there are no direct data on total available and consumption of a material for a process, the mass balance equation (1) developed in Section 2 will be used.

However, for most material categories except alumina and unwrought aluminium, there are insufficient data to infer the stock changes although the industry is aware of the large amount of stock in the system (Harris, 2003, *pers. comm.*). Where stock changes can be inferred from available data, they need to be compared with demand in order to relate their size. Therefore, the *stock change level* of a material category is defined as the stock change divided by the domestic demand of the material. Finally, the relationship between the flows of different material categories will also be examined to show the interactions between them.

4.4.1 Bauxite

Import, export and extraction: There has been no extraction of aluminium ore and bauxite in the UK in the time period studied. Consequently, the country has relied entirely on bauxite imports to meet its alumina production requirements. Alumina production, however, disappeared in the UK in 2000. Bauxite imports were around 400 kt per year between 1958 and1971, before decreasing to a level of 200-300 kt between 1972 and 1996 (Figure 4.4). Imports plummeted to below 10 kt after 1997, with the exception of an increase to 163 kt in 2001. Despite having no domestic extraction, there was a small quantity of bauxite exports, less than 1% of imports. Bauxite exports stopped in 1993. According to Alfed, as alumina production stopped in the UK in 2000, the imported bauxite in 2001 was exported to Ireland for alumina production and was not recorded in the statistics.

Stock changes: Roughly four tonnes of bauxite are used to produce two tonnes of alumina, which in turn produces one tonne of aluminium (Alfed, 2003). In most years, when comparing alumina with bauxite supply, alumina production consumed 20-40% of the supply, except during 1997-1999. This indicates that there was considerable bauxite accumulation before 1997, which was depleted during 1997-1999 when imports were small. However, there are no statistics of bauxite stock at the aluminium makers and no data are available for bauxite consumption in alumina production. Similarly, no data are available for the exact material yield rate from bauxite to alumina. It is therefore difficult to quantify the stock change of bauxite in the UK over the years, although the industry is aware of the existence of bauxite stocks.



*Export series in red scaled to the right hand axis

Figure 4.4 Bauxite import, export and alumina production

4.4.2 Aluminium scrap

Import, export and consumption: Aluminium scrap is another major raw material source for aluminium production in the UK. Aluminium scrap is normally used to produce unwrought aluminium. Unwrought aluminium produced from scrap is called *secondary aluminium* in the industry. The scrap, mainly prompt scrap, is also directly used in producing semi-fabrications, which are called *wrought products* in the industry.

Data from WBMS and Alfed contain large discrepancies on the total scrap consumption in the aluminium industry. Although the two sources agree on secondary aluminium production, from which the scrap consumption was inferred by using a yield rate, they disagree on the amount of wrought products produced from scrap. The difference between these two estimates of total scrap consumption is shown in Figure 4.5.

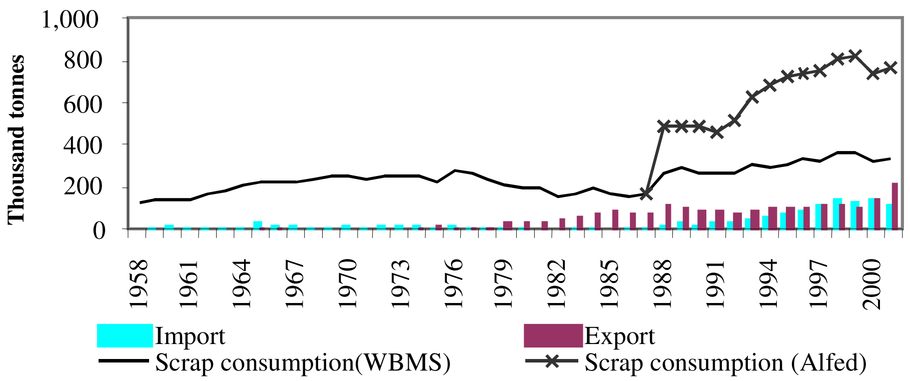


Figure 4.5 UK aluminium scrap consumption and trade

Figure 4.5 shows that scrap imports into the UK during 1958-1991 were very low, less than 30 kt per year. Imports then increased aggressively to about 100 kt per year. Aluminium scrap exports demonstrate a similar pattern, but saw an earlier increase than imports. There has been a sharp increase in scrap exports since 1979, from a level of 10 kt per year to more than 100 kt per year in the 1990s. In 2001, the country imported and exported 110 and 208 kt of aluminium scrap respectively. Since 1979, with the exception of 1997-1999, UK has been a net exporter of aluminium scrap.

The huge volume of scrap trade, compared to consumption, is due to the fluctuation of scrap prices and the increasing profit that may be obtained by storing and trading scrap at the right time. It is also due to the relatively expensive land transport in the UK compared to cheap marine freight.

Aluminium scrap consumption in secondary and wrought aluminium production increased from an annual 132 kt in 1958 to 325 kt in 2001 according to WBMS, or 700 kt in 2001 according to Alfed. The scrap consumed included both internal and external scrap. According to the Alfed survey, about 450 kt of external scrap, namely prompt and EOL scrap, constituted input to remelters and refiners. However, there was a big decrease between 1977 and 1988, with an annual consumption low of about 160 kt. Scrap consumption returned to a 270 kt per year level in 1988, approximately the same level as that in 1977. Both statistics indicate the industry saw a constant increase in scrap consumption between 1988 and 1999. There was a slight decline in scrap consumption in 2000 and 2001. Overall, Alfed statistics indicate rapid growth in secondary aluminium while the WBMS statistics show rather slow progress.

Scrap imports amounted to less than 10% of the consumption in the UK between 1958 and 1990, signifying that during this period more than 90% of the scrap consumed was from domestic recycling. Scrap imports have increased considerably since 1990, amounting to around 20% of consumption, which indicates that about 80% of the consumption is from domestic recycling.

Scrap stocks: There are no data on aluminium scrap stock or the amount of received scraps at the refineries and remelters. Consequently, it is impossible to derive the stock changes.

4.4.3 Alumina

Production, import and export: Even before its closure in 2000, **t**he UK did not have a strong alumina production base (Figure 4.6). Alumina production was around 100 kt per year during the study period, while imports increased dramatically from a level of less than 10 kt per year in the 1960s to around 600 kt per year since 1973. This reflects the fact that the major alumina plant in the UK, in Newport, was closed in the 1960s and that smelter-grade alumina has not been produced in the UK since the 1970s, when the Burnt Island plant in Scotland switched to producing alumina for chemical uses only.

Stock changes: No data are available on alumina stocks and their consumption in downstream primary aluminium production. Nevertheless, there are records of the yield rate of alumina. Two tonnes of alumina produces approximately one tonne of aluminium; therefore, the material coefficient factor is 0.5. With this coefficient factor, the alumina stock changes can be inferred using the approach explained in section 2.2. Figure 4.7 shows the inferred stock changes of alumina between 1967 and 2001.

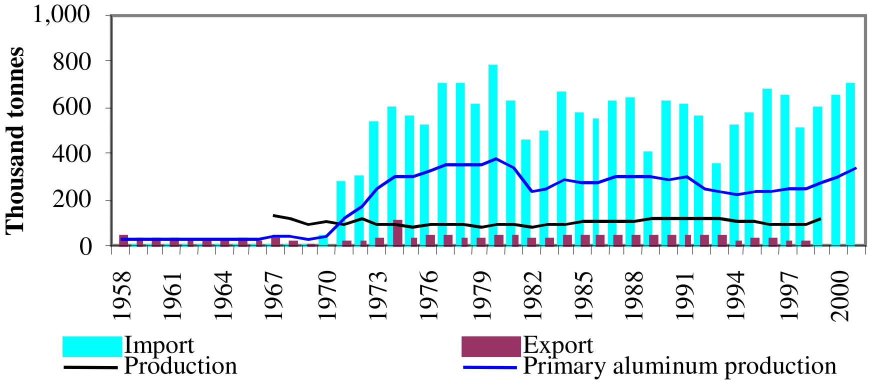
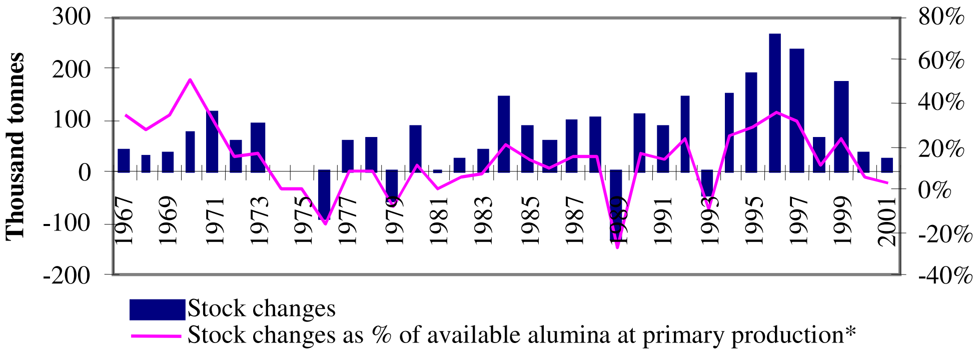


Figure 4.6 Alumina production and trade, primary aluminium production

The industry has suffered from declining prices due to the sluggish demand, oversupply and mounting inventories since early 1990s. Consequently, smelters respond to excess stocks by reducing production (Section 1.7) and this causes a delayed cyclical movement in production and stock changes due to long supply chain lead times. EAA (2003) reported that monthly primary aluminium stocks held by European smelters and integrated fabricating plants were about 600 kt between 2000-2003, with a variation of ± 60-80 kt. Although there are no similar data on alumina stocks, it is conceivable that they would display a similar trend, as alumina production and supply are driven by primary aluminium production.



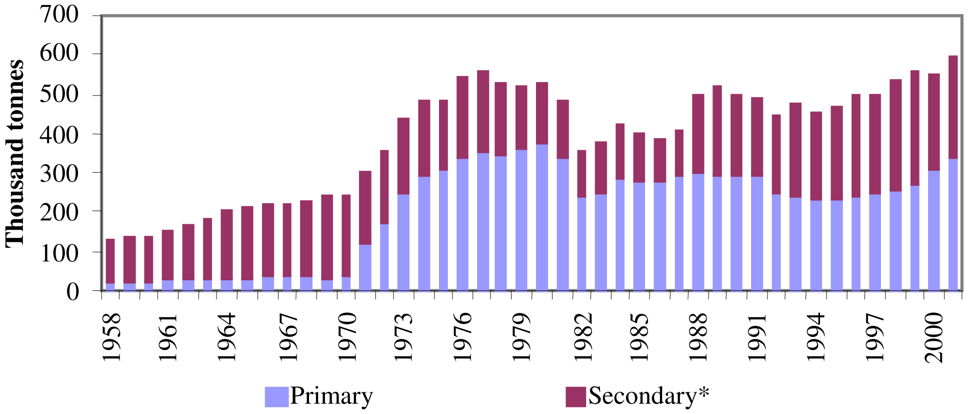
*Purple line scaled to right hand axis. Available alumina at primary production in the country is the value pf alumina production plus imports minus exports
Note: the figure may be distorted due to the international trading which is carried out with apparent imports and exports of alumina sometimes never arriving or leaving the UK.

Figure 4.7 Alumina stock changes

Figure 4.7 indicates that most of the time the stock changes amounted to around 25% of the total available alumina at the primary aluminium production. However, as it is impossible to establish whether this is a real and exact variation in stock, or is due deficiencies in the data, it is suggested that this figure is only an indication of alumina stock movements rather than a precise estimate.

4.4.4 Unwrought aluminium: ingots, billets and slab

Production, import and export: At the primary smelter, alumina is transformed into unwrought ingots, billets and slabs by electrolysis and casting processes. At the refiners, scrap can also be remelted and processed into unwrought aluminium. Figure 4.8 shows the contribution of primary production and refiners in the unwrought aluminium production in the UK.



*Secondary production refers to refiners' production in the UK only

Figure 4.8 Primary and secondary unwrought aluminium production in the UK

The figure shows that between 1958 and 1970, the refiners contributed approximately 80% of the total unwrought aluminium output in the country. The share from primary smelters increased rapidly in the early 1970s, from 40 kt per year in 1970 to 300 kt per year in 1974. The rapid growth in primary smelters during the 1970s was followed by a drop in 1982 to a level of 250 kt per year, which was maintained until 2001. On the other hand, the production of secondary smelters oscillated around 150-250 kt per year throughout 1958-2001. Most of the primary aluminium produced in the UK was in the form of billets and slabs added as molten metal directly into the alloying furnaces, from which the rolling slabs and extrusion billets are cast.

The overall unwrought production saw a progressive growth from an annual 130 kt in 1958 to 250 kt in 1970. This was followed by an aggressive increase during 1970-1977, to 550 kt per year. Production declined to 350 kt in 1982 whereby a new cycle of growth started. In 2001, the country produced 590 kt of unwrought aluminium, predominantly in ingot form.

UK production alone has been unable to support the growing domestic demand for unwrought aluminium. There are substantial imports and exports of unwrought aluminium. This is partially due to the European and global nature of the aluminium business. The UK production could not economically produce all of the products that are required domestically. Figure 4.9 shows the production and trade flows of unwrought aluminium recorded by the WBMS and Alfed.

The two sources agree on primary and secondary smelter production most of the years, except a small and visible difference between 1978 and 1980. They disagree on imports in 1992 and 1996, and on exports during 1999-2000.

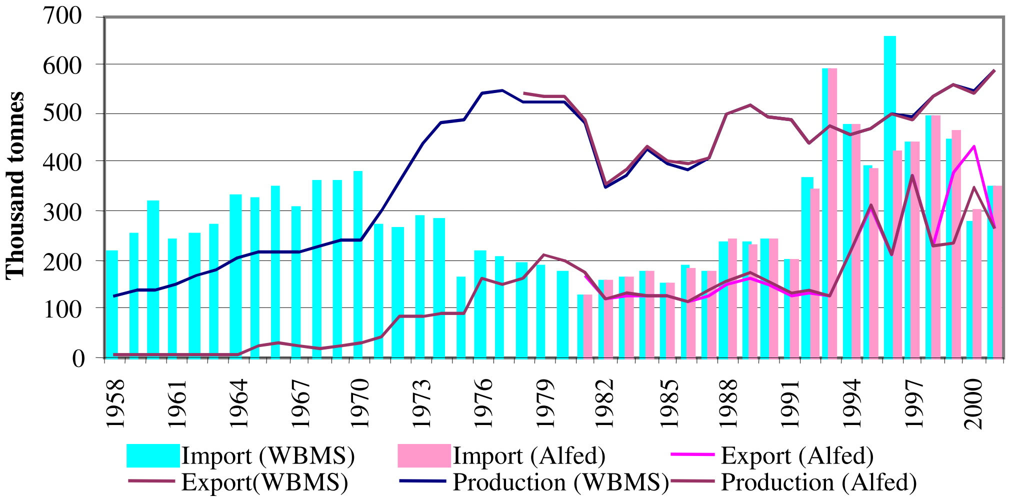


Figure 4.9 Unwrought aluminium production, exports and imports

This discrepancy is thought to be due to time differences in reporting the statistics between these two sources, as data from the WBMS are based on data submitted by Alfed. The reporting time for Alfed to WBMS is normally around April for the previous year, when data are not complete and include some estimation. Alfed publishes its annual report for the previous year much later, when the data are more complete and accurate.

As a result, in the time series study, data from Alfed are used for production between 1978 and 2001 and for imports and exports between 1982 and 2001. Data from WBMS is used for other years.

The UK imported unwrought aluminium in the form of ingots at a level of around 300 kt per year between 1958 and 1970, accounting for more than 60% of domestic demand (i.e. import plus production minus export). The import then decreased to about 200 kt per year during 1971-1991, contributing to 30-40% of domestic demand. This was due to the increase in the domestic production at that period. The import has increased rapidly since 1992, at around 400 kt per year, but with significant fluctuations. Sometimes the import even overshot domestic production during 1993-1996. Exports demonstrated an overall increasing trend despite a decline and flat period experienced during 1981-1994. According to Alfed statistics, the UK exported and imported 260 and 350 kt of aluminium in 2001 respectively.

Stock changes: There are WBMS statistics on the consumption of unwrought aluminium from primary smelters and refiners. Unwrought aluminium stock changes can therefore be calculated by using the equation (1) in Section 2. Figure 4.10 shows the recorded and inferred stock changes.

It is understandable that some aluminium has to go into stocks in order to keep them at a normal level[13] in relation to consumption. In the study of the "*identified stocks*" (i.e. combined LME and producers' stocks, the key indicator of stock levels), King (2001) revealed that in the slack market of the early 1980s, the identified stocks worldwide amounted to 80 days of world consumption.[14] In the late 1980s, under the tight market conditions, these stocks reduced to around 30 days' world consumption; while a huge increase in the early 1990s brought identified stocks up to 90 days' consumption. However, King's study was on global aluminium stocks and it is unclear how the stock level has changed in individual regions and countries.

Figure 4.10 indicates that the UK aluminium industry showed good performance in managing the unwrought aluminium material flows between 1958 and 1992, with the stock changes amounting to less than ±10% of the demand. The stock changes were about ±20-40 kt per year over that period. The data suggest, however, that the industry then experienced high fluctuations of stock holding. However, the industry believe that the fluctuation of stock is an artefact introduced by the data, with some international trade

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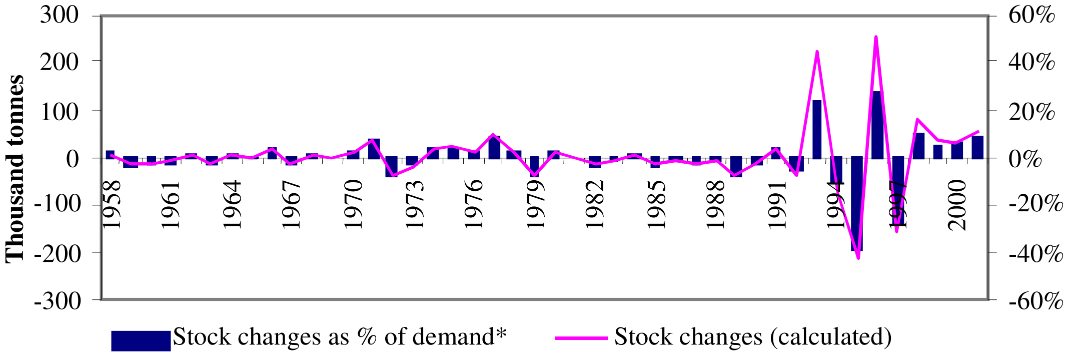
[13] The normal level of identified stocks for the future, defined by King (2001), is around 45 days' world consumption or 13% of world annual consumption.

[14] Days' consumption is calculated as: stocks x (annual consumption / 365).

misrepresented; dramatic stock changes were not in fact experienced by the aluminium producers.



Note: the figure may be distorted due to the international trading which is carried out sometimes with apparent imports and exports of aluminium never arriving or leaving the UK.

Figure 4.10 Stock changes of unwrought aluminium

4.4.5 Semi-fabrications and castings

Production, import and export: There are no data on the production of semi-fabrications and casting. Both data sources use despatches from the producers as equivalent to production. During the period 1978-2001 when there were also statistics available from Alfed, both sources agreed on the production for 1978-1987, 1992-1995 and 2000-2001, but diverged in other years (Figure 4.11).

The import and export data from the two sources also show a gap of around 10-100 kt. Most of the time, WBMS has high import and export values with lower production figures. Despite this discrepancy, most values from both data sources are within the same order of magnitude, except for the production in 1999. The discrepancy is partially due to reasons explained in Section 4.4.4, and partially due to different interpretation of Customs and Excise data, as the two sources independently compile Customs and Excise data for their annual statistics. A similar data strategy is used for semi-fabrications and casting as that for unwrought aluminium.

Similar to unwrought production, semi-fabrication and casting production experienced growth between 1958 and 1978 but with a smoother gradient. The production increased from 300 kt in 1958 to 500 kt in 1978. After this, there was a decrease to around 400 kt per year until 1983, when production picked up again. In 2001, the country produced approximately 700 kt of semi-fabrications and castings.

The figure also shows that the contribution to the total from the remelters, which use predominantly prompt scrap, has increased from 60% in the 1980s to almost 90% in the 2000s. Given the fact that only about 20% of the input to remelting furnaces is primary aluminium ingots, this implies that UK production of semi-fabrications and castings is essentially distinct from the primary aluminium production and trades.

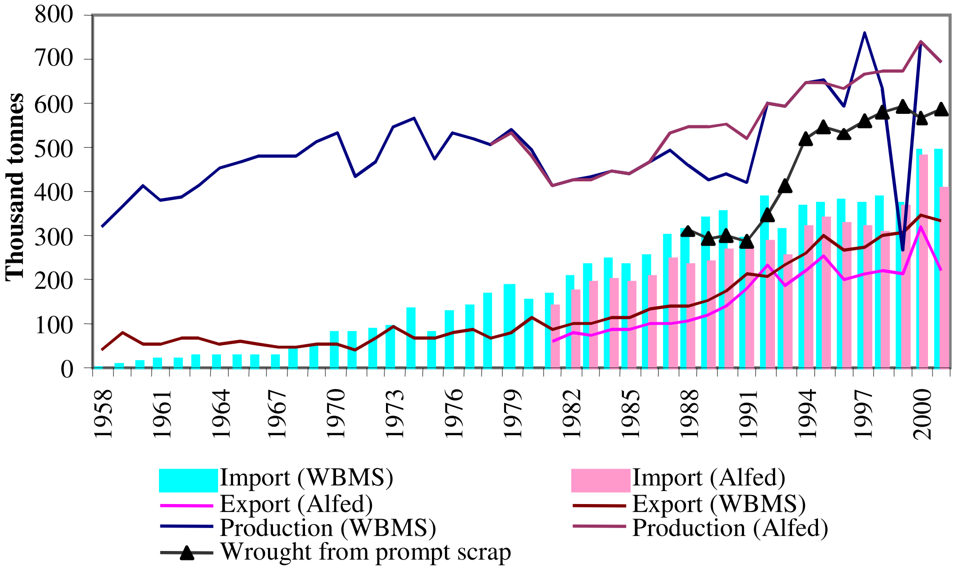


Figure 4.11 Production and trade in semis and castings

There were more exports than imports between 1958 and 1970, although both imports and exports over that period were small compared to production, amounting to less than 80 kt. Both have increased since 1970. The imports, with a sharper growth gradient, outstripped export by around 100 kt. When considering the domestic demand as production plus import minus export, the contribution of imports to meet domestic demand for semi-fabrications and castings in the UK increased from 1% in 1958 to 60% in 2001.

Stock changes: There are no statistics on the stocks of semi-fabrications and castings held either by producers, stockists or other distribution channels. There are also no data on the consumption of aluminium semi-fabrications and castings in the downstream manufacturing sectors. Therefore, it is impossible to derive the stock changes trend from the available data.

4.4.6 New goods

Production, import and export: Aluminium semi-fabrications and castings are the final products of the aluminium industry, as well as the raw material input for downstream manufacturing such as automotive, packaging and construction sectors. The aluminium supply chain starts to become complicated at this point, as there are countless kinds of new goods where aluminium products are incorporated. The material flows at this supply chain stage starts resemble a "V" shape with limited raw materials input and wide variety of finished products as output (Macbeth and Ferguson, 1994). The complexity of material flows in new goods fabrications and manufacturing demands a simplified material flow account of aluminium in new goods.

It is assumed in this study that the delivery of aluminium to downstream new goods manufacturing sectors in a year is the consumption of aluminium in these sectors in that year. The consumption minus amounts of prompt scrap generated is assumed to equal the amount of aluminium that flows into the use phase in that same year.

The two data sources show a significant divergence in aluminium consumption in new goods manufacturing, as shown in Figure 4.12. The difference between the two sources was about 50 kt during 1978-1985, after which the difference grew to 100-200 kt. WBMS divides downstream manufacturing into 9 sectors, with fairly transparent classifications, and gives aluminium consumption by the individual sectors. On the other hand, Alfed classifies semi-fabrications and castings into three groups: rolled, extruded and cast products. Alfed also reports the delivery profile of each of these three products to downstream manufacturing sectors.

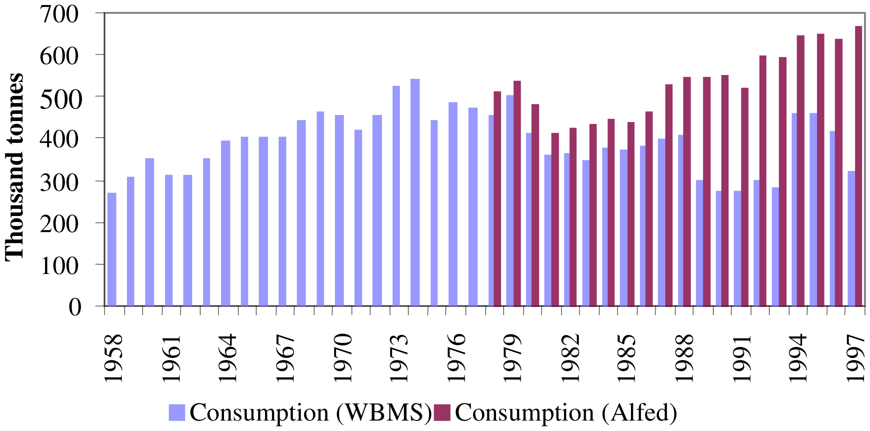


Figure 4.12 Aluminium consumption in UK manufacturing, Alfed and WBMS data

The manufacturing sectors categorised by Alfed are: engineering; building and construction; transport; packaging; consumer durables; and others. The consumption of the three products to downstream sectors in comparison with production is illustrated in Figure 4.13.

The figure shows that rolled products made the largest contribution to consumption, with an increasing trend in both production and consumption of rolled products. This is possibly related to the fact that aluminium ingots move around the world, while rolled products are traded within Europe and extruded products are transported only within the UK. The versatility of rolled products wins more applications in the downstream manufacture over extruded and cast products.

The average share of rolled, extruded and cast products (include production, export and imports) consumed in the downstream manufacturing sectors over time are shown in Figure 4.14. The delivery profiles to the individual sectors are also shown in Table 4.5.

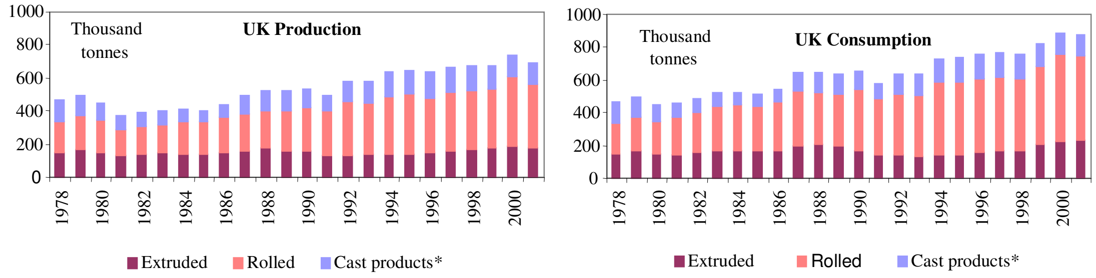


Figure 4.13: UK production and consumption of extruded, rolled and cast products

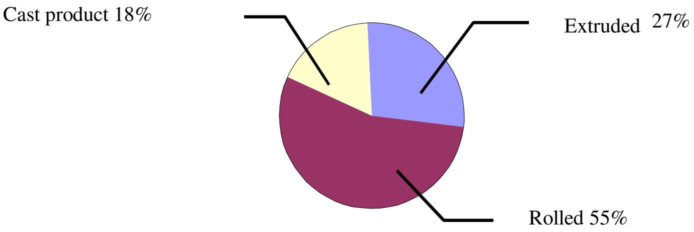


Figure 4.14 Market shares of rolled, extruded and cast products

Table 4.5 Delivery profile of cast, rolled and extruded products

	Cast	Rolled	Extruded	Prompt scrap
Transport	75 %	11.00%	13%	0.2
Building/Construction	7 %	20%	54%	0.05
Engineering	14 %	12%	14%	0.05
Packaging		41%		0.1
Consumer durables		4%		0.05
Others	4 %	12%	19%	0.1

The values in the table, however, are European averages. This table, together with consumption of the three aluminium products groups and prompt scrap arisings in the individual manufacturing sectors, can be used to derive aluminium incorporated in new goods in the UK. The prompt scrap arisings, as a percentage of total consumption in new goods manufacturing, are also included in Table 4.5 and are explained in Section 4.5. Figure 4.15 summarises the market share of the individual sectors for all aluminium products.

Data from Alfed are used in the analysis of new goods material flows, as the WMBS use data from Alfed and it is unclear how the data have been manipulated. With the information on aluminium content in different categories of new goods, the import and export of aluminium contained in the new goods can also be derived. Figure 4.16 shows the production, import, export and derived domestic demand of aluminium in new goods.

Imports of aluminium in new goods were around 400 kt per year during 1978-1993, and then grew from 500 kt in 1994 to 850 kt in 2001. Assuming imported aluminium in new goods is used for meeting domestic demand, imports accounted for 60-80% of domestic demand.

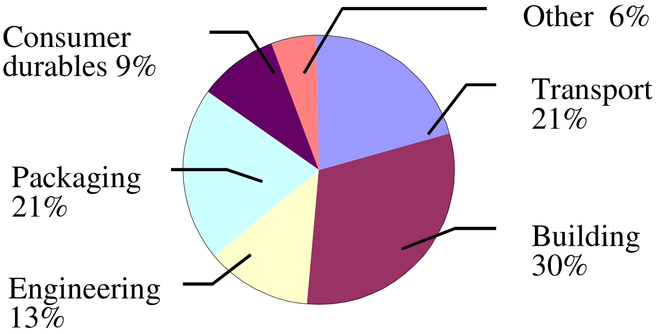


Figure 4.15 Market split for aluminium consumed in different industry sectors in the UK in 2001.

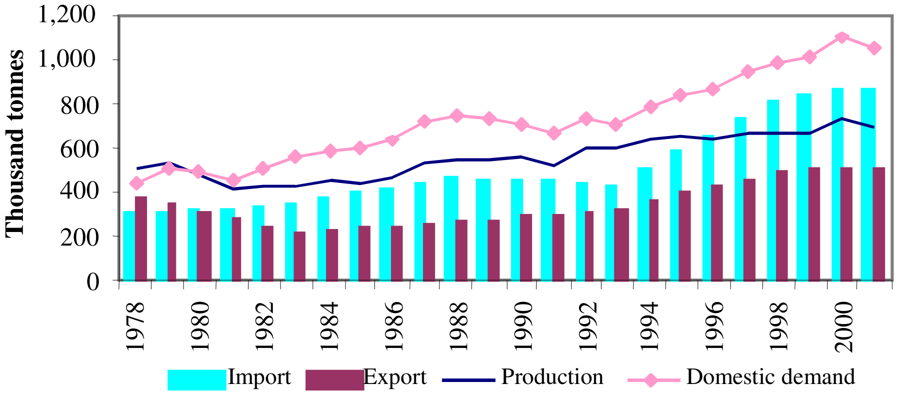


Figure 4.16 Production, trade and domestic demand of aluminium in goods.

Production demonstrated a slow growth, from 500 to 700 kt between 1978 and 2001. High exports indicate that most of the production of aluminium in new goods is destined for foreign markets. Exports showed a decreasing trend between 1978 and 1983, dropping from 370 kt in 1978 to 200 kt in 1983. Exports then grew to 500 kt in 2001.

4.4.7 Overview of the aluminium supply chain

While the previous sections looked at the material flows of the individual material categories, this section will examine their interactions along the supply chain. Figure 4.17 shows the demand flow, defined as production plus import minus exports, of four material categories. From a supply chain perspective, the demand flow of an upstream material is also the supply flow to satisfy a downstream demand flow (see Section 2). In the figure, data during 1958-1977 are from WBMS, while data from 1978-2001 are mostly from Alfed.

All the flows demonstrate a growth trend, except the demand flow of unwrought aluminium which fluctuates too widely to observe any overall trend. The real trend can be partially distorted by international trading. Apparent imports and exports of aluminium can be carried out sometimes with no aluminium ingots arriving or leaving the UK.

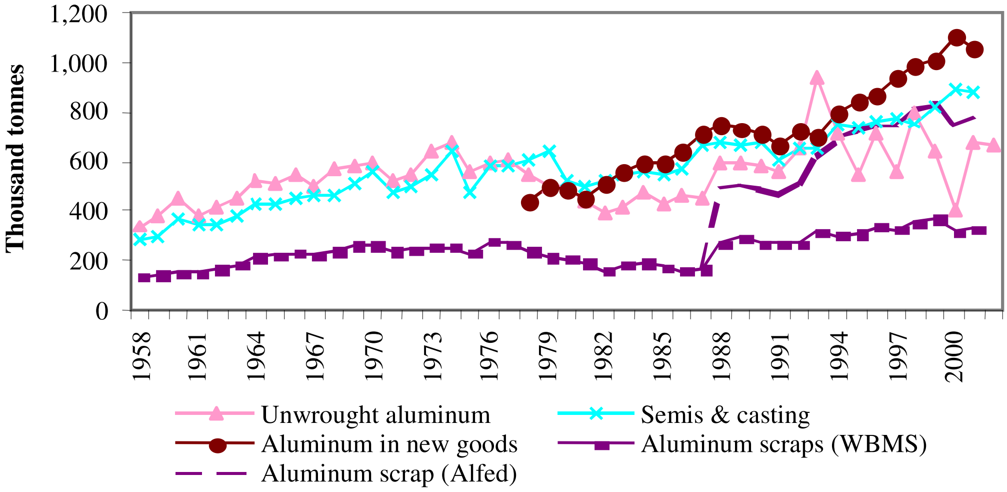


Figure 4.17 UK demand for unwrought aluminium, semis and castings, aluminium in new goods, and aluminium scrap.

The demand flow of aluminium in new goods, the ultimate flow that drives all the other demand flows in the country, has the steepest growth gradient. It grew from 400 kt in 1978 to 1.1 Mt in 2001, indicating a significant domestic demand for aluminium goods. Demand for aluminium semi-fabrications and castings has been lower than demand for aluminium in new goods since 1983. The gap between these two demand flows has grown from 4 kt in 1983 to about 200 kt in 2001.

Compared with the demand flow for aluminium in new goods and semi-fabrication and casting, unwrought aluminium has the lowest volume most of the time, despite a spike in 1993 that outstripped both the other two flows. The violent fluctuation in the unwrought aluminium demand flow highlights the volatility of the market, and the difficulty of managing a material effective and efficient supply chain in the aluminium industries.

In contrast to the rapid increase in the demand flow of aluminium in new goods, the demand for aluminium scrap, based on WBMS data, shows a gradual increase from around 150 kt in 1958, to 350 kt in 2001. This is because secondary aluminium production in the UK was built up incrementally, but not as fast as the speed of scrap arising. However, when based on Alfed data, the scrap demand flow demonstrates a similar growth trend to aluminium in new goods. The two data sources thus give two different pictures with regard to the aluminium recycling activities in the UK, and the data alone do not answer the question whether secondary aluminium production is stable or growing.

Reports and statistics on aluminium recycling in Europe, USA and Japan from OEA[15] show that, in most statistics, secondary aluminium production in the UK only refers to production of secondary unwrought aluminium production. These statistics are similar to the WBMS data. Production of wrought products from mainly scrap is not included. Therefore, the conclusion based on these statistics would be that secondary production is stable, whilst the conclusion based on data from Alfed, which include both secondary unwrought production and wrought aluminium production from the remelters, using mainly prompt scrap, would be that secondary production is growing.

4.5 Aluminium scrap arisings

4.5.1 End-of-life scrap arisings and recycling rate

No data are available on yearly arisings of prompt and EOL scrap. Estimates of EOL scrap arisings have therefore been modelled using the methodology developed in section 2.4. With the consideration of prompt scrap and trade, scrap arisings have been estimated using the model illustrated in Figure 4.18. The aluminium products entering goods manufacturing are divided into six categories: transport, construction, engineering, packaging, consumer durables and other.

Some of the deliveries become prompt scrap during manufacturing and fabrication of goods according to the prompt scrap rate of each sector. The remaining aluminium is incorporated into goods and then either exported or delivered to use in the UK together with imported goods. Aluminium contained in imported and exported goods is shown in Figure 4.19, and the resulting flow of aluminium contained in goods entering use in the UK is shown in Figure 4.20.

The goods stay in use until they have reached the end of their service lives, according to the life span of each category of goods. Table 4.6 gives the information on life spans that have been collected and used in the analysis to model aluminium EOL scrap arisings.

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[15] OEA stands for European Aluminium Refiners and Remelters, an association of firms in the secondary aluminium industry.

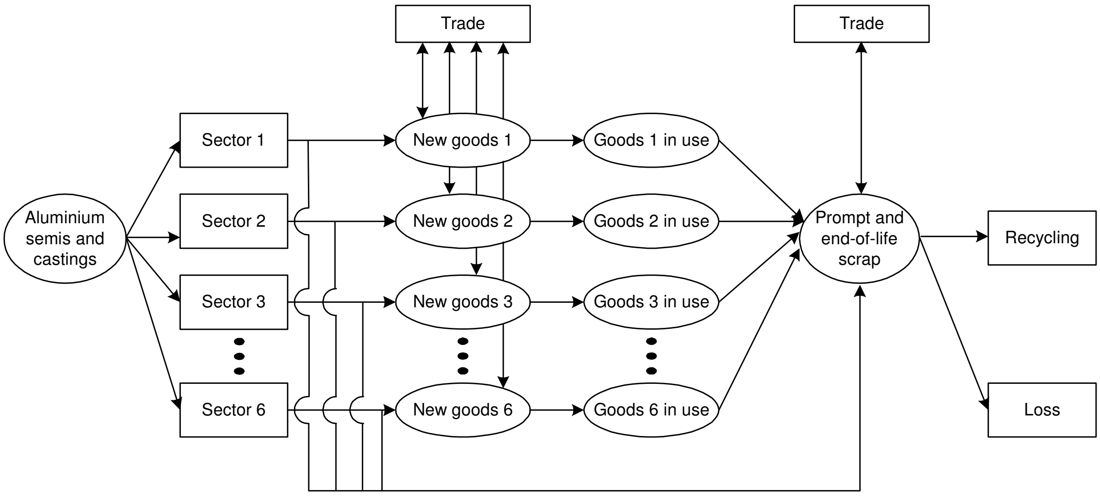


Figure 4.18 Modelling methodology for estimating aluminium prompt and end-of-life scrap generation.

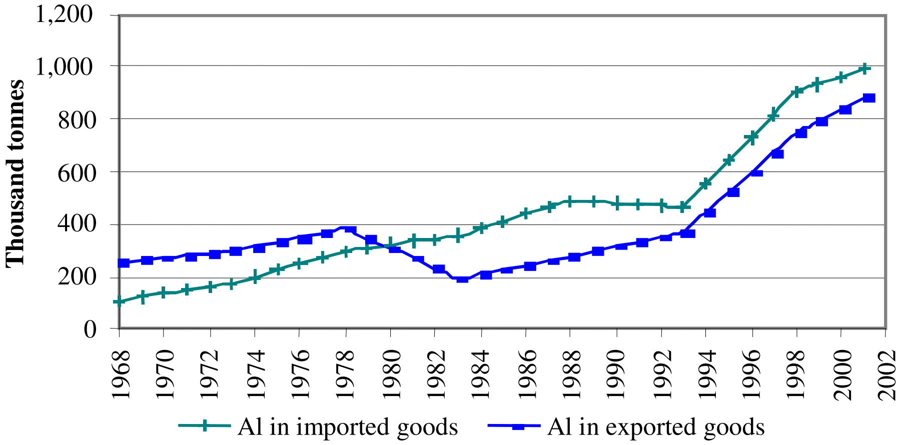


Figure 4.19 Aluminium in traded goods

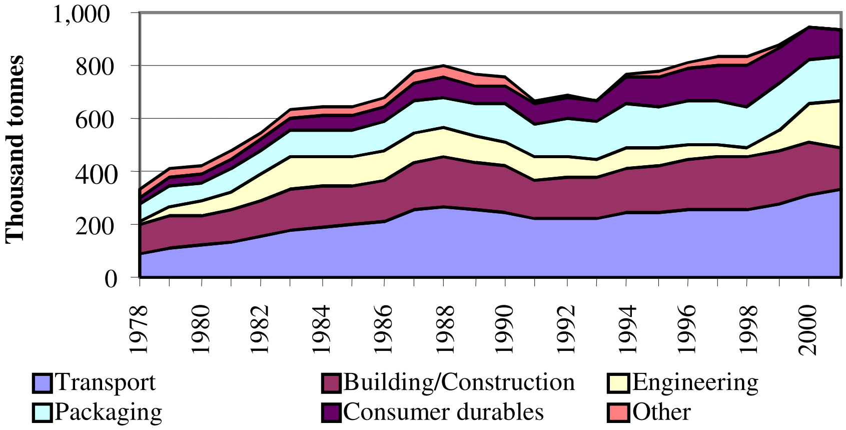


Figure 4.20 Aluminium in goods entering use in the UK

Table 4.6 Life span data used in modelling aluminium end-of-life scrap generation

Goods category	Average Lifespan [years]	Min and max Lifespan [years]	Source
Transport	13	12-15	All data are from Askew (2003)
Building/construction	35	10-60	
Engineering	17	15-20	
Packaging	1	-	
Consumer durables	7	5-8	
Other	10	0-10	

The delay of goods in the use phase has been modelled using three different life span distributions: (1) no distribution (i.e. a fixed number of years); (2) a Weibull distribution; and (3) a lognormal distribution. Data on deliveries to goods manufacturers have been collected from Alfed for the years 1978 to 2001. Data prior to 1978 are not available from Alfed. Data on deliveries to construction prior to 1978 have therefore been taken from *Metallstatistik* for the years 1958 to 1977. The resulting arisings in 2001, using each lifespan distribution, are given in Table 4.7. The table also gives the actual recovery in 2001 and the inferred recycling rate using equation (3) in Section 2.

Table 4.7 Inferred recycling rate for aluminium in 2001 using different distributions

[Tonnes]	**No distribution**	**Weibull distribution**	**Lognormal distribution**
End-of-life scrap arisings	771 874	671 860	668 280
Prompt scrap arisings	80 778	80 778	80 778
Total arisings	852 652	752 638	749 058
Actual recovery	546 198	546 198	546 198
Inferred recycling rate [%]	64	73	73

There is a difference of about 100 kt between the modelled arisings when using no distribution and when using a Weibull or lognormal distribution. Looking at the total inflow of aluminium in goods to use in the UK in Figure 4.20, there are quite significant fluctuations and a clear increase over the past 20 years. The distribution of lives therefore has a significant impact on the inferred recycling rate. Arguably, using a distribution of the life span is more representative of reality. There is a very small difference between the results when using a Weibull or a lognormal distribution.

The results indicate there are about 2-300 kt of aluminium that are not being recovered at present. This aluminium could either be accumulating in use or lost to landfill. Using statistics from Defra and the Environment Agency on how much waste was sent to landfill in 2000/2001, combined with information on how much of this waste is nonferrous metal (Appendix 3.3), it is derived that industrial and commercial waste together with the municipal waste contain about 160 kt of aluminium going to landfill. This excludes the dissipative use of aluminium, which is estimated to be about 40 kt per year. These figures confirm that there are no substantial aluminium flows unaccounted for.

4.5.2 Sensitivity analysis of inferred recycling rate

The parameters that may affect the modelled amount of scrap arisings, and thereby the inferred recycling rate, are the aluminium content in traded goods, the life spans and the prompt scrap rates. These parameters have been changed in order to explore the robustness of the inferred recycling rate.

Table 3.8 shows the influence of the aluminium content of traded goods on the inferred recycling rate. The aluminium content for packaging has not been changed as there are no data reported on trade in packaging – data on packaging trade are included in trade of packaged goods, e.g. juices, food, etc., which do not specify what type of packaging is used. Even small decreases and increases to the aluminium content changes the recycling rate from 73% to 83 and 60% respectively.

Table 4.8. Effect of changing the aluminium content in traded goods on the inferred recycling rate

Al% in traded goods	Original Al%	Decreasing Al% to	Increasing Al% to
Transport	10	5	20
Construction	90	70	100
Engineering	5	1	10
Packaging	100	100	100
Consumer durables	20	10	30
Other	10	5	50
Inferred recycling rate [%]	73	83	60

Changes to prompt scrap rates and life span data are shown in Table 4.9 together with the resulting recycling rates. Increasing and decreasing the prompt scrap rates changes the recycling rates quite dramatically. Life span data have been increased quite significantly (as much as possible considering the relatively short time series available), resulting in an increase of the recycling rate. This is due to growing amounts of aluminium entering use over the years: the longer the life span, the further back in time did the aluminium enter use, resulting in less aluminium being released as scrap in 2001, thus making the recycling rate higher. Similarly, when life spans are decreased, more scrap is released in 2001, and a lower recycling rate is therefore calculated.

Table 4.9 Effect of changing life spans and prompt scrap rates on the inferred recycling rate

Change of parameters	Inferred recycling rate [%]
Increase all prompt scrap rates to 40%	62
Decrease all prompt scrap rates to 2%	75
Double life spans of packaging and consumer durables and increase remaining to 20 years (construction unchanged)	82
Half all life spans	64
With consideration of manufacturing and commercial stock	77

Apart from the possible effects of key parameters on the scrap arisings results as analysed above, another factor that might influence modelled arisings is industrial and commercial stock changes. In the model, it is assumed that the amount of aluminium products delivered to end-users is equal to deliveries to downstream fabrication and manufacturing processes, minus prompt scrap. In reality, however, there are considerable stocks stored by the manufacturers, assemblers, distributors and retailers along the supply chain to buffer market uncertainties.

Manufacturing and commercial stocks have reduced since the 1990s, due to the rapid progress made in manufacturing technology, logistics, information and communication technology. The stock held by manufacturers and distributors is about 10-30% of the costs of goods sold in value annually (Lamming, 1996). The DTI latest survey in the manufacturing industry revealed that the average stock level of an average manufacturer is about 12% of the cost of goods sold annually in 2002 (DTI, 2002). The method used to calculate the recycling rate by considering stock issues is explained in Appendix 3.4. Using the data derived by considering the stock of aluminium, the recovery rate inferred based on the Weibull life span distribution is 77% for 2001 as shown in Table 4.9, which is again close to the original modelled result.

Overall, the model is relatively sensitive to changes to the parameters outlined above. However, even quite dramatic changes to the parameters still produce a recycling rate in the order of 60 to 83%, which is not significantly different from the initial recycling rate of 73% using the original parameters. In conclusion, the inferred recycling rate has to be treated with caution, but it still indicates that a large amount of aluminium is currently not being recovered and that there therefore is room for improving the recovery practices of end-of-life aluminium scrap.

4.5.3 Sectoral recycling scenarios

The total arisings of prompt and EOL scrap arisings in the UK are estimated using the model shown in Figure 4.18. By applying recycling rates to each of the modelled outflows of EOL scrap arisings and comparing the sum of the resulting flows to the actual recycling of scrap in the UK, our results can be validated. However, recycling rates for each goods sector are not readily available, and if they are it is not always clear how they have been derived, which is one of the main reasons for performing this study in the first place. Nevertheless, possible scenarios of recycling using the information available have been created. The recycling rates that are recorded in the literature are given in Table 4.10.

As the three largest markets for aluminium are transport, construction and packaging, the recycling rates of these sectors are probably the most accurate. The recycling rate for engineering is also of the right order as it contains reasonably large, and therefore easily identified and recycled, concentrations of aluminium. The weakest figure is thought to relate to consumer durables. With current and intended legislation, such as the End of Live Vehicles (ELV) and the Waste Electrical and Electronic Equipment (WEEE) Directives, this figure is likely to become more accurate and better monitored.

Two possible scenarios of recycling are shown in Table 4.11. In the first scenario the literature based recycling rates in Table 4.10 are multiplied with the modelled arisings; the resulting amount of recycled scrap is a little less than the reported amount of recycled scrap: 519 kt compared to 546 kt. In the second scenario, the recycling rates are increased slightly so that the modelled amount of recycled scrap is equal to the reported amount of recycled scrap: 546 kt.

Table 4.10 Literature based recycling rates for UK aluminium goods

Goods category	Recycling rate [%]	Source
Transport	95	All from Alfed (2003)
Construction	95	
Engineering	75	
Packaging	34	
Consumer durables	50	
Other	50	

Providing that the reported recycling rates are in the right order, this suggests the model is producing reasonable results. It also indicates that the largest losses of aluminium originate from EOL engineering goods, packaging and consumer durables. The industry is well aware of the loss of aluminium from used beverage cans (UBCs), which is why it launched a national aluminium can recycling scheme in 1989. The recycling rate has since risen from only 2% in 1989 to 42% in 2001 (Alupro, 2003).

Table 4.11 Scenarios of different recycling rates for the different sectors in 2001

Goods category	2001 scrap arisings [tonnes]	Recycling rates Scenario 1 [%]	Recycling rates Scenario 2 [%]
Transport	232980	95	98
Construction	42510	98	99
Engineering	93990	70	85
Packaging	137010	34	34
Consumer durables	95850	45	60
Other	19580	45	60
Prompt scrap	80778	100	100
Inferred amount of recycled scrap [tonnes]		*518 985*	*546 916*
Actual scrap recycling 2001 [tonnes]		546 198	546 198

4.6 Summary of current aluminium flows

The previous sections have explained how data have been compiled for the flows of aluminium in the UK reaching back several decades. All data compiled are available in Appendix 4.3 at the end of the report. Figure 4.21 shows an overview of all the flows of aluminium for the year 2001. The following text summarises the flows in this year, using the compiled data together with necessary modelling and assumptions as reported in the previous sections.

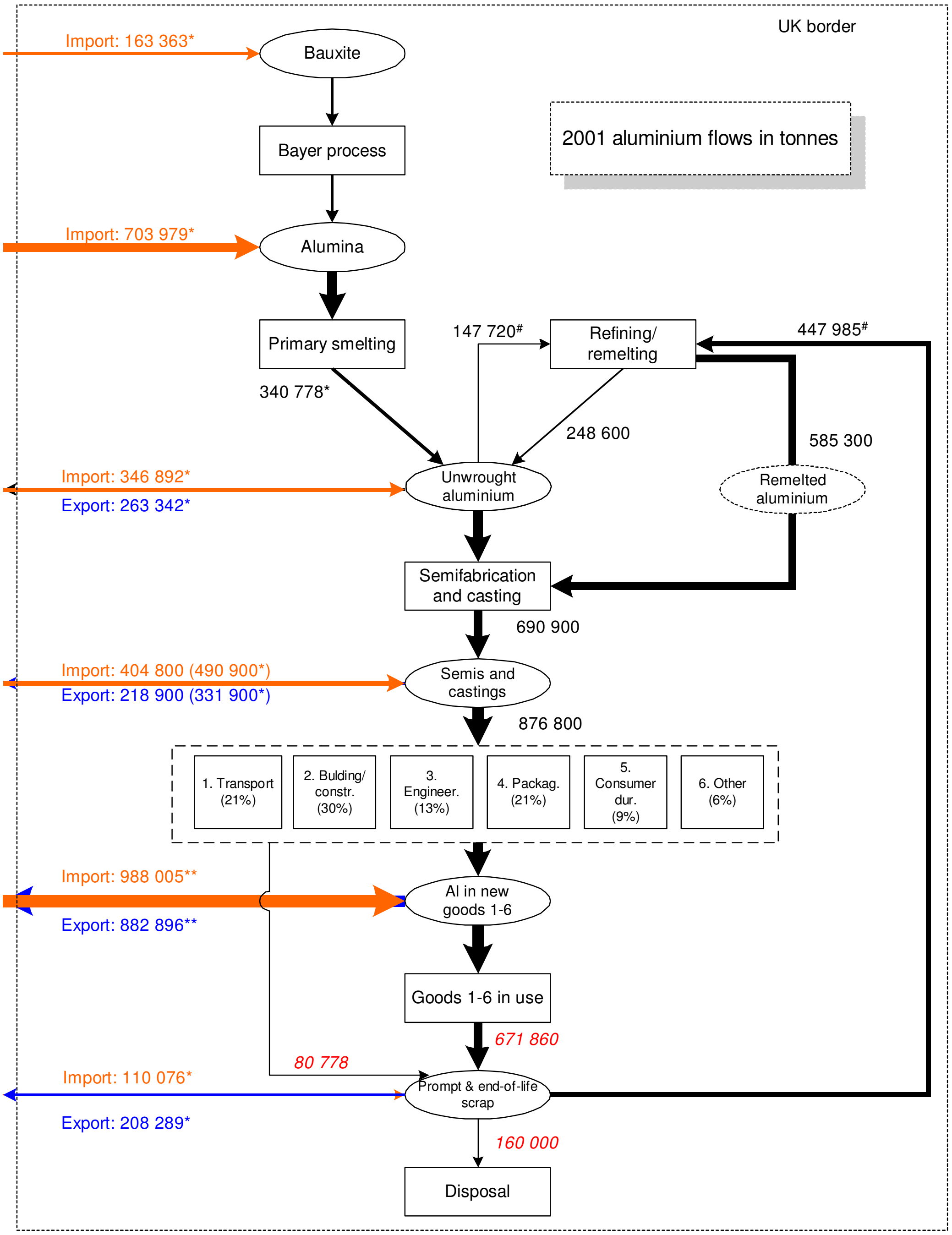
All alumina used in primary aluminium production in 2001 was imported, as alumina production stopped in the UK in 2000. There was however still around 160 kt of imported bauxite, which was destined for export. In 2001, about 340 kt of primary aluminium and 830 kt of remelted aluminium were produced in the UK. Further down the chain, one third of the aluminium semis and castings produced in the UK were exported, and imports of aluminium semis and castings products are about twice the size of exports.

About 9 kt of aluminium semis and castings were delivered to UK goods manufacturers and fabricators in 2001. Most of this aluminium went into construction, followed by the transport and packaging sectors. These three sectors currently consume more than 70% of the total deliveries of aluminium semis and castings in the UK. Just less than 10% of the total aluminium deliveries to UK manufacturers was turned into prompt scrap and recycled back into the system.

There is a substantial amount of aluminium in goods imported into and exported from the UK. In 2001, more than 800 kt of aluminium contained in goods were exported from the UK, and almost 1 Mt of aluminium in goods were imported. This massive trade in goods containing aluminium is the result of an increasing trend over the last ten years.

About 620 kt of EOL scrap was released in 2001. Together with available prompt scrap arisings this makes up about 700 kt of available scrap. 200 kt of this scrap was exported and recycled abroad, and 450 kt was recovered and recycled domestically. A further 160 kt ended up in landfill. The recovery of aluminium scrap arising in the UK therefore seems to be working relatively well, in that more than 70% of the scrap arisings is being recovered and recycled. However, there is still room for improving recovery and recycling practices of aluminium in the UK.

In this chart, flows may not balance themselves across different processes and material categories due to delays caused by manufacturing and industry stock holding practices; due to figures coming from two different and sometimes diverging sources; and due to the existence of officially unrecorded flows. Especially, as mentioned in 4.4.1, the 163 kt imported bauxite in 2001 were exported for alumina production overseas, according to Askew (2003). Alumina produced in the UK was not for primary aluminium production (see 4.4.3) but for other industries. The flow of primary unwrought aluminium into refining/remelting accounted for 20% of total input to the remelters and refiners (see 4.4.2), and the figure of 147,720 tonnes of primary aluminium going into remelting was based on Alfed survey of domestic remelters and refiners in 2001.



*World Bureau of Metal Statistics
**2000 figures
Alfed survey on remelters and refiners input in 2001
Note: flows may not balance themselves across different processes and material categories due to the delays caused by manufacturing and industrial stock holding practice.

Figure 4.21 System overview of UK aluminium flows in 2001

5 VALUE CHAIN ANALYSIS METHODOLOGY

This section will expand on the concept of the value chain and look at how it has been applied in other areas of study, and introduce the methodology of value chain analysis that will be used in this report.

5.1 Value chain analysis: origins and applications

Concepts of 'value chains' can be traced to different sources and applications. The term is used often rather loosely, referring not only to flows of money between parties but also flows of products and information. However, the work of Michael Porter (Porter, 1985) has had a key influence on value chain thinking and helped establish a common framework and vocabulary for its study, primarily within business and management science.

Value chain analysis, as it is most commonly applied, is a strategic management or cost accounting tool used to diagnose and enhance a company's competitive advantage. The analysis does this through a breakdown of an organisation's strategic activities (so called value activities), an examination of their costs, and the streamlining and coordination of the linkages of those activities within the 'value chain'. This exercise can enhance the efficiency of a company's internal operations; the efficiency of the operations of several actors in an industry-wide value chain; and aid decisions concerning investments and expansions.

The concept has also been applied to studies of international trade from a political economy framework of development and underdevelopment, with a focus on the different actors in a chain and their differential capacities for wealth appropriation within the chain. Both types of applications of VCA however are concerned with identifying ways in which incomes or profits can be sustained over time.

5.1.1 Porter's value chain

Superior productivity, which is the key to competitive advantage, is derived from low production costs or the ability to attain a price premium for superior products. Porter offers the *value chain* as a tool to diagnose competitive advantage, through a systematic examination and disaggregation of a firm's activities into separate but interrelated *value activities* (Figure 5.1).

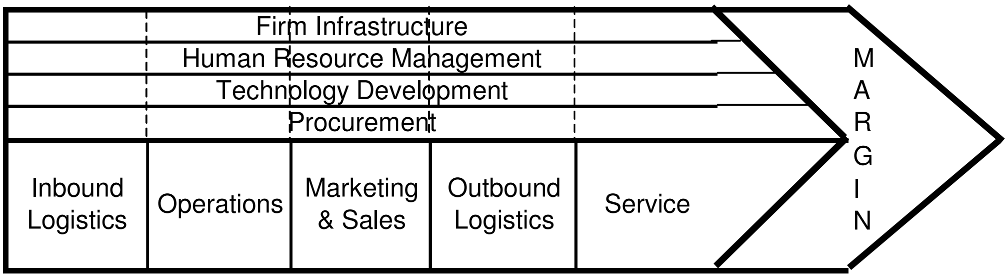


Figure 5.1 Porter's generic value chain

Porter suggests nine generic categories of technically or physically distinct value activities. The five primary activities are inbound logistics, operations, marketing and sales, outbound logistics and service). In addition, there are the support activities: firm infrastructure, HRM, technology development and procurement. These activities are linked together in different ways for different companies. Disaggregating them is thought to help companies better understand the behaviour of costs as well as realised or possible sources of differentiation.

Competitive advantage stems not only from these value activities in themselves, but also from the way they are related to each other by *linkages* within the value chain. The same product can be manufactured in many different ways, and identifying the linkages between activities involves an examination of how a value activity affects or is affected by the other activities. For example, changing the shape or quality of pre-cut steel sheets may reduce scrap later on in the process or minimise the number of defective products. Similarly, strengthening quality assurance during early stages of manufacture may help reduce post-sales service. Identifying, optimising and coordinating these linkages can result in cost savings and competitive advantage.

As these value activities are rarely the same as conventional accounting classifications, a major area of application of value chain analysis is therefore in strategic cost accounting/management accounting, where companies proceed by identifying their value activities, determining which ones are strategic, tracing costs to those activities and then using that information to improve their management while streamlining, outsourcing or abandoning other, non-strategic activities (Donelan and Kaplan, 1998). In this application, it is analogous to certain aspects of environmental accounting, in which environmental costs and revenues are identified within the conventional accounting system (Gray *et al.*, 1993).

5.1.2 Moving beyond the firm

Porter also acknowledges the importance of *vertical linkages* – linkages between a company and its suppliers and buyers – and suggests that establishing industry value chains will help firms position themselves favourably within their industry. This need not be at the expense of the other companies within the industry, as value chains of different actors can be configured so as to optimise overall performance and coordination between firms.

Undertaking value chain analysis at the industry level helps companies make strategic decisions, such as if and how to expand current activities, where to focus capital investments, and helps to identify suitable suppliers and buyers.

Womack and Jones (1996) have a somewhat more specific industry-wide focus for their 'value stream' concept, as well as being concerned with waste in a broad sense. They are influenced by the Japanese concept of *muda*, which means not only waste but wasteful behaviour, such as making mistakes which must later be rectified, engaging in unnecessary process steps, producing unwanted products or products which do not meet customer needs, and losing productivity due to delays.

To counter such sources of waste, and to remove the actual and opportunity costs associated with them, they advocate a 'lean management' style, which goes beyond the firm and examines the entire supply chain associated with a specific type of product. Wastefulness appears at many stages of the production chain, and to remove inefficiencies at one stage it is often necessary to involve upstream actors, as for example the energy needed by a product in use is determined at upstream design stages.

Their study of the value stream of a can of cola delivered to and sold by Tesco supermarkets is an interesting example of wasteful behaviour, particularly in the form of time-delays in a can's journey from bauxite to supermarket shelf. After the retailer had streamlined its own ordering, storage and delivery systems, they needed to improve the systems of the upstream companies involved in this particular value stream in order to realise further efficiencies. As more than 85% of the costs associated with typical supermarket products are outside the retailers' direct control, there is an incentive for engaging with other actors in the industry chain to improve overall efficiencies and cost savings throughout the value chain.

5.1.3 Material flows, environmental impacts and economic dimensions

There is a wealth of business, accounting and management literature on the theory and application of value chain analysis, but most of it relates to how one firm can improve its own relative position within the industry rather than how the overall strengths of the industry could be improved. This situation presents a clear parallel with examples of environmental management initiatives. The experience with waste minimisation exercises and resource productivity improvements at the level of individual companies is not hugely widespread but substantial enough to warrant reasonably good documentation[16], whereas examples of combined efforts of groups of companies or whole industries are much more limited. While internal environmental management is effective and necessary,

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[16] For examples of waste minimisation, see www.envirowise.gov.uk, and for resource productivity improvements von Weizsäcker *et al.*, 1996, and Hawken *et al.*, 1999.

products and materials have environmental impacts *throughout* their life cycles, all stages of which need to be addressed for effective reductions in environmental impact.

Pollution and waste frequently stem from the inefficient use of inputs, the utilisation of toxic materials, and unnecessary process steps or activities. As seen in the example of canned drinks, a company has *direct* control only over a limited number of areas that could improve the environmental performance of a product, whereas it has *indirect* influence over the sorts of actions that could bring wider benefits, or 'systemic efficiencies', throughout the life of the product (e.g. logistics, packaging, transportation, design, recycling systems).

Certain forms of environmental management – recycling systems, industrial ecology inspired production, life-cycle oriented environmental management, supply-chain management – are by their very nature inter-organisational. There are barriers to engaging in such inter-organisational environmental practices, notably the economic cost of organising and governing the cooperation, which exceeds the cost associated with establishing internal environmental management practices (Sinding, 2000). These transaction costs may be particularly high as different material flows may require their own governance structures. However, from an environmental perspective results can be very positive, and there may also be financial benefits arising from an optimisation of material flows, such as identifying unnecessary or wasteful production steps.

A company's position in a chain – upstream or downstream – also influences its ability to contribute to resource-saving initiatives and benefit from them. Inefficient systems can mean that saving energy in the furthest downstream part of the chain could save up to ten units of fuel at the power plant. These cascading effects through a value chain, and the interconnectedness of environmental effects make it easier for vertically integrated companies to implement these sorts of system savings (de Groene and Hermans, 1998). For other chains, with less vertical integration, the main contractor would need to govern and support the smaller organisations (Pesonen, 2001) so that all parties could realise the advantages of systemic resource efficiencies.

5.1.4 Combining material flows, environmental impacts, and values

MFA, LCA and VCA all look beyond the unit of the individual firm to the wider economy, and often examine the same problems from different angles. The three tools have distinct units of measurement: tonnages, environmental impacts, and money units respectively. This limits their individual usefulness as evaluation tools for decisions concerning sustainable production or consumption, as any effort concerning cleaner production or resource productivity will have to consider all these dimensions (Wrisberg *et al.*, 2002).

Looking at a hypothetical example of production and consumption of leaded/unleaded automobile batteries, one study compares material flows, life cycle assessments and partial economic equilibrium models (Bouman *et al.*, 2000), in terms of their usefulness for deciding on three different policy options for countering environmental damage: materials substitution, air emissions reduction, and reducing the amount of lead being disposed of in landfills. The study concluded that MFA is better at identifying technical options that in principle could solve a problem; LCA can tell whether such technical measures could lead to other environmental problems; and the partial equilibrium analysis helps identify the most efficient way of implementation.

Despite the recognition that inclusion of economic effects would increase the applicability of the analyses and their strength as evaluation tools – “whether this is right or wrong, the only decision support system with virtually a global significance is price” (Krozer and Vis, 1998) – the literature search revealed little theoretical or empirical work in this area. However, a few studies have undertaken ‘hybrid analyses’, connecting material flows and their economic dimensions (De Groene and Hermans, 1998; Williams, 2003); material flows and environmental impacts (Narayanaswamy *et al.*, 2003); or environmental impacts and economic dimensions (Clift and Wright, 2000).

5.1.5 Value chain analysis and the environment

The two concepts of a chain of activities/actors in production and of economic competitiveness strike fundamental chords with certain aspects of environmental management, and there is a clear link between economic competitiveness and environmental performance through resource productivity improvements. Reducing pollution and maximising profit share basic principles of enhancing productivity and minimising inputs, waste and wasteful behaviour. Both the literature around economic competitiveness and inter-organisational environmental management stress the need to identify hidden or unanticipated costs, the need for information and cooperation between and governance of different actors in the chain; and the potential to realise system-wide efficiencies benefiting parties throughout the production or value chain.

Examining the value chain is not merely a descriptive exercise, but it is also an analytical tool. Value is not a policy neutral concept: government policy, including environmental regulations and taxes, affect the shape and form of industry value chains. Values are also constantly changing due to competitive pressures, which are increasingly global in nature. Effective industry-wide value chains require governance by the involved parties, and stem from systemic efficiencies associated with changes through the whole chain rather than from efficiencies of individual entities within the chain (Kaplinsky, 2000).

The focus on linkages within actors in the chain, on governance, and on the potential for systemic efficiencies should aid considerations of where and how different parties should intervene to promote more sustainable forms of production and consumption. The value chain provides a framework for coherent and integrated responses by industry as well as policy-makers. The combined MFA-VCA can therefore be used to inform scenarios of different kinds. Changing waste management regulations and levels of energy or landfill taxes will impact on the costs and levels of profitability at the different stages of the chain, and will have an impact on the economic attractiveness of recovery and reuse of materials. The attractiveness of different levels of reuse and recycling will also be influenced by material ownership structures within the chain.

5.2 Value chain methodology

5.2.1 Resource productivity and efficiency

Economic activity is associated with resource flows related to the extraction, production, consumption/use, and disposal of materials and products. Many current environmental problems are rooted in the size of society's material throughput, suggesting that a *decoupling* of economic growth and resource flows is needed to reduce environmental impacts while improving quality of life.

Such a decoupling hinges on improvements in resource productivity and efficiency, defined broadly as doing more with less. Decoupling can be either relative or absolute. Relative decoupling means that productivity improvements – fewer inputs required per unit of output – have been realised but total inputs continue to increase as output increases. Absolute decoupling refers to the situation in which there is an overall reduction in required inputs – whether through significant productivity improvements or through a decrease in outputs, or a combination of the two.

While technical progress since industrialisation has improved the efficiency with which natural and human-made resources are employed, this decoupling has been relative rather than absolute, that is, the efficiency gains have largely been outweighed by growth in the scale of the economy, and there has been an absolute increase in both resource inputs and emission and waste outputs. This is sometimes referred to as the 'rebound effect' (Binswanger, 2001). The scale of the economy and the pressing nature of many environmental problems mean that resource productivity improvements must now be radically increased.

It has been suggested that global use of nature should be halved, but that this can be achieved whilst doubling wealth through resource efficiency improvements by a factor of four (von Weizsäcker *et al.*, 1998). The 'Factor 10' proponents argue for an absolute reduction in resource use by a factor of ten for industrialised countries. Resource productivity improvements are key to sustainable development as defined by the UK government (DETR, 1999).

Measures of Resource Productivity and Efficiency

For the purposes of clarity, this report will distinguish between *resource productivity* and *resource efficiency*. Resource efficiency is measured as a basic ratio of two physical variables. It can be measured as a ratio between material output, M_o, and material input, M_i, such as useful material output per total material input:

$$M_o/M_i = \text{material efficiency}$$

or some other physical ratio of interest for the issue being studied, such as useful output produced per amount of waste or pollution generated, or useful output per input of energy, E_i:

$$M_o/E_i = \text{energy efficiency}$$

It can also be measured as a ratio of some kind of welfare indicator, Y, and a material or environmental indicator, such as economic output per unit of natural resource input:

$$Y_o/M_i = \text{material productivity}$$

or economic output per amount of pollution or waste generated, or per input of energy:

$$Y_o/E_i = \text{energy productivity}$$

It is this latter type of definition that is advocated by the Government through the Performance Innovation Unit's report on resource productivity (PIU, 2001), as a measure of the efficiency with which the economy generates added value from the use of nature, and which can therefore tell whether economic growth is decoupling from resource use.

This latter definition is also analogous to the concept of labour productivity, which is measured as GDP or value added per worker or per hours worked, and which is used by the Treasury as a key indicator on UK productivity. Two labour productivity indicators will be used in the analysis: economic labour productivity, which is value added per worker, and material labour productivity, which is material output per worker.

Resource productivity as measured in this way is therefore a generic indicator for measuring progress towards a less material intensive economy. Choosing variables to operationalise the indicator will depend on the unit of analysis (firm, sector, region, whole economy); the purpose of analysis (benchmarking, waste minimisation, effects of economic structural change); as well as data availability constraints. For analysis of resource productivity trends at the firm level, a range of indicators has been suggested (see WBCSD, 2000), while at the sectoral and national levels the choices are more constrained. At the national level, available statistics are GDP or value added per unit of greenhouse gas emissions, or per units of energy used. Improving measurements of resource productivity has been identified as a priority (PIU, 2001). Also, any resource productivity indicator provides only a relative measure, and would need to be supplemented by measures of absolute trends in resource flow growth in order to establish whether the decoupling is absolute or only relative.

Eco-efficiency is a concept related to resource productivity, interpreted as a broad management strategy for decoupling economic activity from resource use and pollution

(Schmidheiny, 1992). Resource productivity, and its inverse of resource intensity, can therefore be seen as measures of eco-efficiency (EEA, 1999). However, the terms productivity and efficiency are often used interchangeably and confusingly in this field.

Resource productivity and efficiency in the steel and aluminium industries

This project has examined resource productivity and efficiency trends in the iron and steel and aluminium industries; using time series data on material and energy inputs and outputs for measures of material and energy efficiency, and time series data on material and energy flows in combination with data on economic output for measures of material and energy productivity.

The analysis sheds light on broad resource productivity and efficiency trends in the two industries over the last two to three decades. Specifically, it has attempted to answer the following questions:

- Are the iron and steel and aluminium industries improving their material efficiency, that is, are they creating more useful output with fewer material inputs;

- Are the iron and steel and aluminium industries improving their energy efficiency, that is, are they creating more useful output with less use of energy;

- Are the iron and steel and aluminium industries improving their material productivity, that is, are they creating more value with fewer material inputs;

- Are the iron and steel and aluminium industries improving their energy productivity, that is, are they creating more value with fewer energy inputs; and

- Is any observed decoupling relative or absolute?

The trends in resource productivity and efficiency for iron and steel and aluminium are examined in Sections 6.1 and 7.1 respectively.

5.2.2 Value Chain Mapping

Value chain analysis, as applied in this project, starts with the explicit recognition that the stocks and flows of iron/steel and aluminium have associated economic values. As materials are transformed and passed along a chain of production, fabrication, use/consumption and reuse or disposal, the value of the materials is either enhanced or reduced. All the various material flows of iron/steel and aluminium investigated by this project have associated economic values.

One concern of this report is to identify and map the magnitude of these changes in material values throughout the UK economy, as well as identifying the processes which hold the greatest value-creating or value-diminishing potential. It will introduce the methodology of value chain analysis for this purpose, and map the current (2001) material and value flows associated with iron/steel and aluminium in the UK (Sections 6.2 and 7.2). Sections 6.3 and 7.3 will add to the limited body of existing work that combines material with economic considerations by looking at other possible value chain analysis applications for iron and steel and aluminium respectively.

Mapping the value chain

As a first step in mapping the value chain, a diagrammatic overview of the industry is created, with respect to flows of principal materials through the productive chain and their values; flows of inputs and their values; and flows of outputs and their values. Figures 5.2 and 5.3 shows these overviews for the UK iron and steel and aluminium industries respectively.

The diagrams and their associated nomenclature take account of the fact that broad material categories, such as crude steel or unwrought aluminium, have different values depending on the quality of the material, which is a function of the specific mixture of required inputs and production processes (e.g. alloys of different specifications); the source of the material (UK or imported); and the destination of the material (reused within a plant, sold, or disposed of as waste).

There are six main material categories of iron and steel: iron ore; pig iron; crude steel; iron and steel industry products; new goods containing iron and steel; and scrap. Similarly, there are six main material categories of aluminium: bauxite; alumina; aluminium; semis and castings; new goods containing aluminium; and scrap (see Table 5.1).

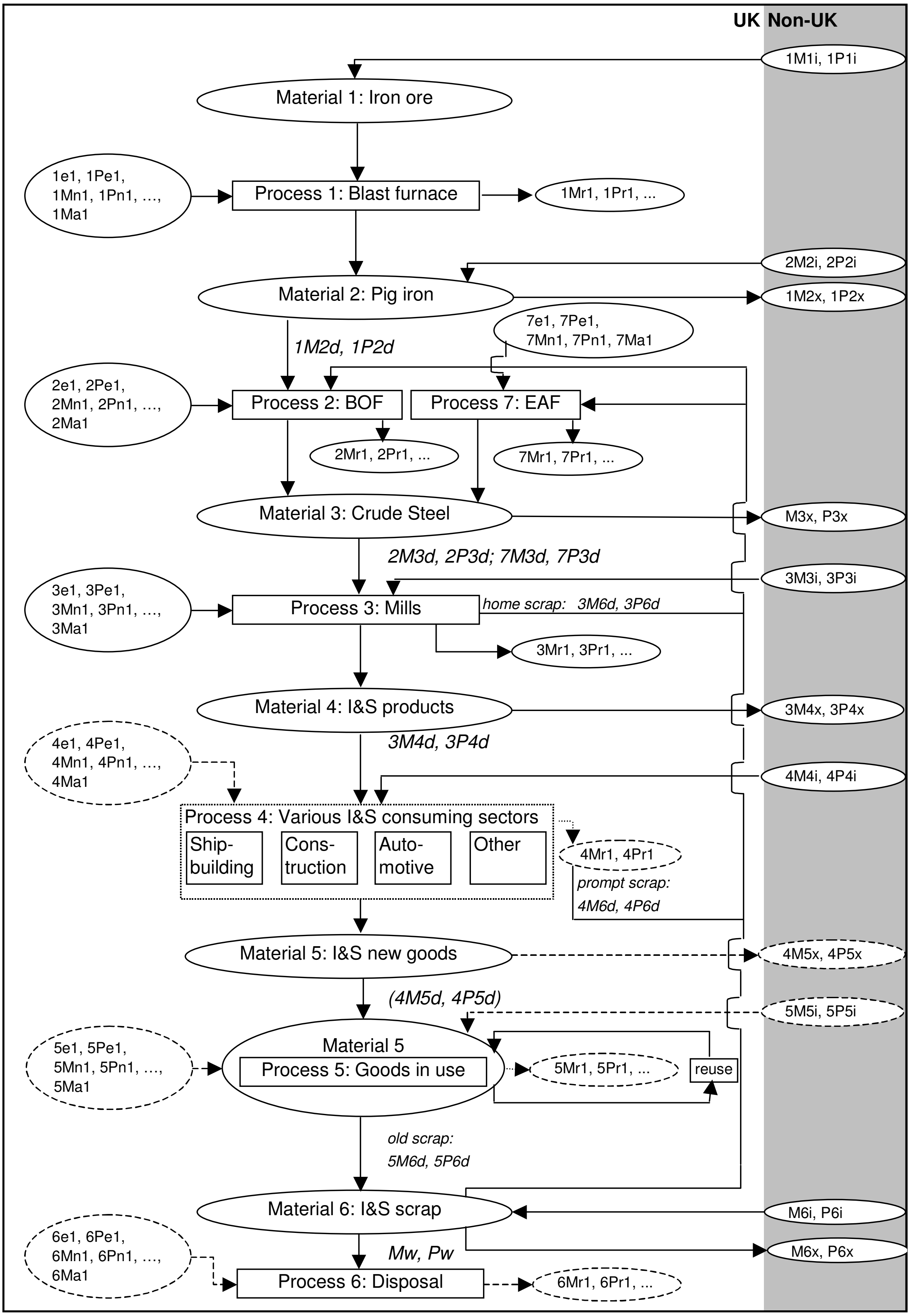

Figure 5.2 Iron and steel material and value flow overview

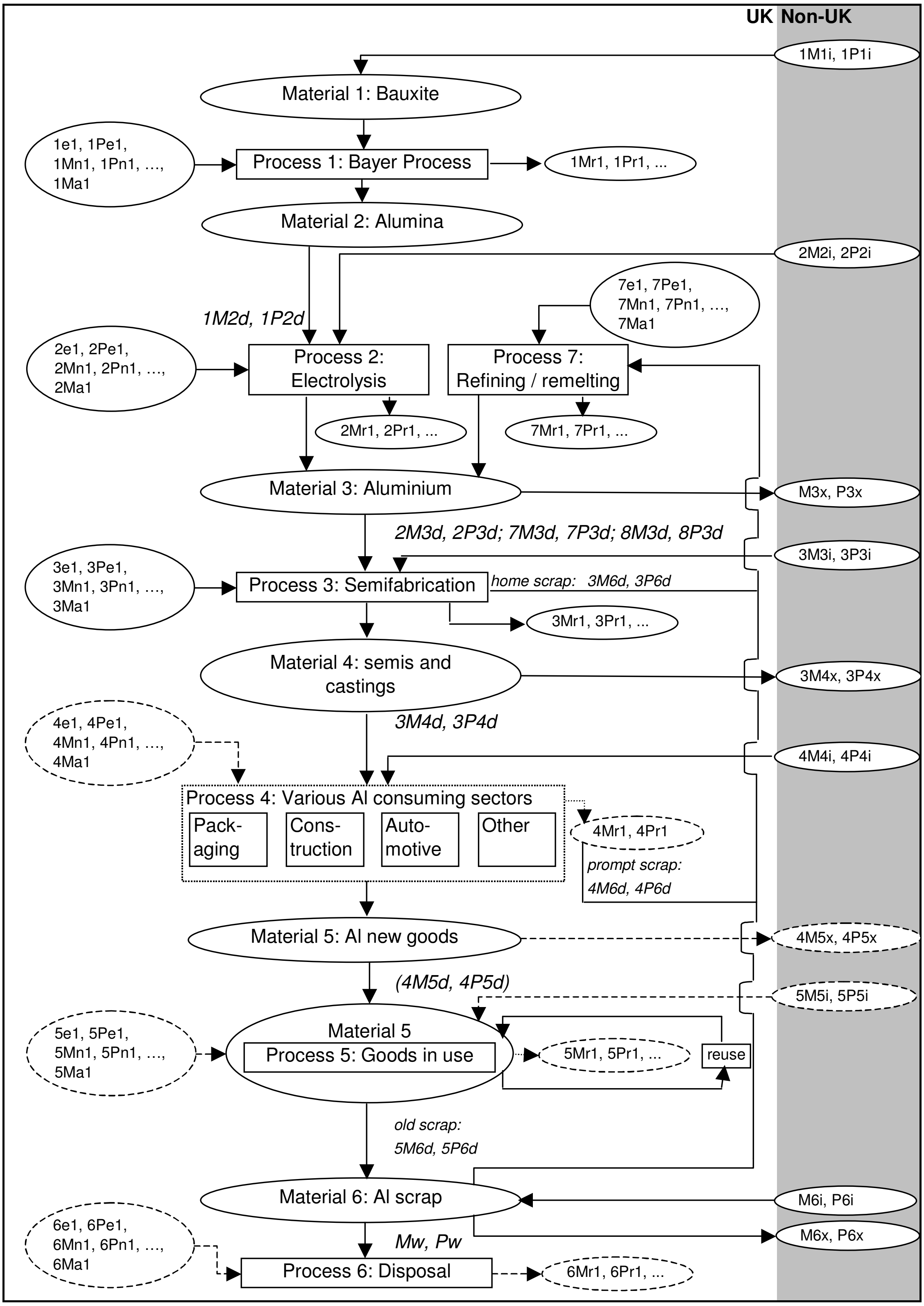

Figure 5.3 Aluminium material and value flow overview

Table 5.1 Material and value flow overview nomenclature

Processes			**Materials**		
	Iron and steel	Aluminium		Iron and steel	Aluminium
Process 0	Mining	Mining	Material 1 (M1)	Iron ore	Bauxite
Process 1	Blast Furnace	Bayer Process	Material 2 (M2)	Pig iron	Alumina
Process 2	Basic Oxygen Furnace	Electrolysis	Material 3 (M3)	Crude steel	Aluminium
Process 3	Semi-finishing in mills	Semi-fabrication	Material 4 (M4)	Steel products	Semis and castings
Process 4	Various manufacturing	Various manufacturing	Material 5 (M5)	New goods / goods in use	New goods / goods in use
Process 5	Use / consumption	Use / consumption	Material 6 (M6)	Scrap	Scrap
Process 6	Waste disposal	Waste disposal			
Process 7	Electric Arc Furnace	Refining / remelting			

Abbreviations	**Explanation**
e = energy M = material Mn = ancillary material Ma = atmospheric material Mr = residual material (waste, emissions, valuable by-product) Md = material for domestic market Mi = imported material Mx = exported material Mw = material (unspecified) for waste disposal P = price	First number denotes *process*: In case of *outputs* (d, r, x), the process the materials come *from*; in case of *inputs* (a, e, i, n), the process the materials go *to*. Second number denotes *material*: 1M2d, is domestic output of material 2 (pig iron or alumina) from process 1; M6x is material 6 (scrap) destined for export.

In the diagrams, where ovals represent stocks of materials and rectangles processes, materials are further detailed with the help of letters denoting whether the material is an input to a process, or an output from a process. On the input side, *e* denotes energy inputs; *Mn* ancillary materials; *Ma* atmospheric materials; *Mi* imported material. As far as outputs are concerned, a distinction is made between materials destined for the domestic market (*Md*), for export (*Mx*), for waste disposal (*Mw*), or whether the outputs are residual materials (*Mr*), such as wastes, emissions, or valuable by-products. While iron and steel and aluminium scraps are clearly examples of such valuable residual materials, this material category is included among the main material categories, as it is a material of specific interest for the project.

Referring back to the diagram nomenclature, the first number denotes the *process*: in the case of inputs (materials denoted by *a*, *e*, *i*, or *n*), the process that the material is going into, or in the case of outputs (*d*, *r*, or *x*), the process from which the material has resulted. The second number denotes the material. Therefore, *1M1i* in Figure 5.2 denotes imports of material 1, iron ore, into process 1, the blast furnace, and *1P1i* denotes the price of those same imports. In Figure 5.3, *1M1i* denotes imports of material 1, bauxite, into process 1, the Bayer process, and *1P1i* denotes the price of those same imports. Further down, *M6x* is material 6, scrap, destined for export, although the process from which it stems is undefined as available trade statistics do not contain that level of detail. Scrap, M6, illustrates well the point about broad material categories having different values: scrap from process 5 is old scrap, whereas scrap from process 4 is prompt scrap, and scrap from process 3 is home scrap. Therefore, these three categories have different values, denoted by *5P6d*, *4P6d*, and *3P6d.*

For the ancillary material and energy inputs and residual outputs, the diagram does not specify the exact materials, although a closer examination would reveal these. For example, for the blast furnace process the specific energy inputs would include electricity (*e1*) and natural gas (*e2*), the ancillary materials would include sinter (*Mn1*), pellets (*Mn2*), coke (*Mn3*) and so forth. Typical outputs from this particular process, apart from pig iron which is of course the principal product in this step, are slags (*Mr1*), various types of dust (*Mr2*), and carbon dioxide (*Mr3*). For electrolysis the specific energy inputs would be mainly electricity (*e1*); the ancillary materials would include anodes (*Mn1*), sulphuric acid (*Mn2*), cathodes (*Mn3*) and so forth. Typical outputs from this particular process, apart from aluminium, are carbon (*Mr1*), skimmings and dross (*Mr2*), and carbon dioxide (*Mr3*).

Some ovals and lines are drawn with dotted lines, indicating that the materials they represent and their flows will not be considered, or only partially considered, by the project. For example, the only residual output from process 4, manufacturing, of interest for the project is prompt scrap, all other outputs will be ignored. For the imports and exports of new goods only the mass of metal contained in them will be considered, the value will not be explored as attempting to apportion a value to the metal content only of the good in question would be meaningless.

Values of material categories

Mapping the current flows of values of materials through the UK iron and steel and aluminium industries requires not only knowledge of what the materials are – the *M* aspect of the diagram, which is the subject of Sections 3 and 4 – but also an appreciation of the values - the *P* aspect – of the broad material categories. Note that ‘value’ in this project refers only to actual monetary values of materials, and does not attempt to put a value on positive or negative environmental (or other) externalities.

As mentioned above, values for broad material categories can vary substantially depending on the exact composition of the materials, their source and their destination. Additions of different alloying elements are relatively unproblematic from a mass balance point of view, however, for the purposes of a value chain analysis, adding foreign elements to steel or aluminium can greatly increase their values. While crude steel and aluminium are both internationally traded commodities and in this respect reasonably homogenous commodities, the generic name can also disguise important differences in quality and value. Also, while adding alloying elements in the production stage increases the value of the resulting intermediate product, these same elements can have the opposite effect at the end-of-life stage in the value chain, where alloying elements can contaminate the scrap. In general, values have been established for the broad material categories used in the material flow analysis, unless data existed to allow a further value breakdown where this was deemed important.

To enable a mapping of the current iron and steel and aluminium value chains, values for the main material categories were collected from a number of different sources, such as Her Majesty’s Customs and Excise (HMCE) trade data; the EU survey of manufactured products, ProdCom; the London Metal Exchange (LME) and other metal traders; and industry sources. The current value chains for the UK iron and steel and aluminium industries are detailed in Sections 6.2 and 7.2 respectively.

Clearly, the framework and methodology described here can be used to focus on any specific class of materials and their associated values. This project has not collected data on the inputs of ancillary materials or on the residual outputs of production; however, Sections 6.3 and 7.3 present ways of combining publicly available information on residual outputs (waste, greenhouse gas emissions) from iron and steel and aluminium production with data on their values and destinies. These outputs are interesting from a public policy perspective, as waste generation and greenhouse gas emissions are topical environmental policy areas. They are also interesting from an industry point of view, as companies can save money by recycling rather than disposing of residual materials as waste, and make money from selling them as by-products.

6 IRON AND STEEL VALUE CHAIN ANALYSIS

6.1 Iron and steel resource productivity

This section examines resource productivity and efficiency trends in the iron and steel industry; using both time series data on material inputs and outputs for measures of material and energy efficiency, and time series data on material and energy inputs in combination with data on economic output to create measures of material and energy productivity.

The analysis sheds light on broad resource efficiency and productivity trends in the industry over the last two to three decades. Specifically, it has attempted to answer the following questions:

- Is the iron and steel industry improving its material efficiency (M_o/M_i), that is, is it creating more useful output with fewer material inputs;
- Is the iron and steel industry improving its energy efficiency, that is, is it creating more useful output with less use of energy (M_o/E_i);
- Is the iron and steel industry improving its material productivity, that is, is it creating more value with fewer material inputs (Y_o/M_i);
- Is the iron and steel industry improving its energy productivity, that is, is it creating more value with less use of energy (Y_o/E_i); and
- Is any observed decoupling relative or absolute?

6.1.1 Material efficiency (M_o/M_i)

As mentioned in Section 5.2.1, one of the key issues in establishing resource efficiency and productivity measures is data availability, as not all businesses or industries collect mass data on the sorts of variables one might wish to examine, over the time periods one might wish to study.

The ISSB collects a range of mass data related to the UK iron and steel industry, however, data on inputs consumed in mass terms[17] are available for crude steel production only. This enables a time series comparison between the amount of crude steel produced, in tonnes, and the amount of materials consumed in this process, also in tonnes. Figure 6.1 shows the material efficiency associated with crude steel production in the UK, as well as the total resource use and total production output (as indices).

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[17] Iron, scrap, oxides, finishings, fluxes and fettling materials.

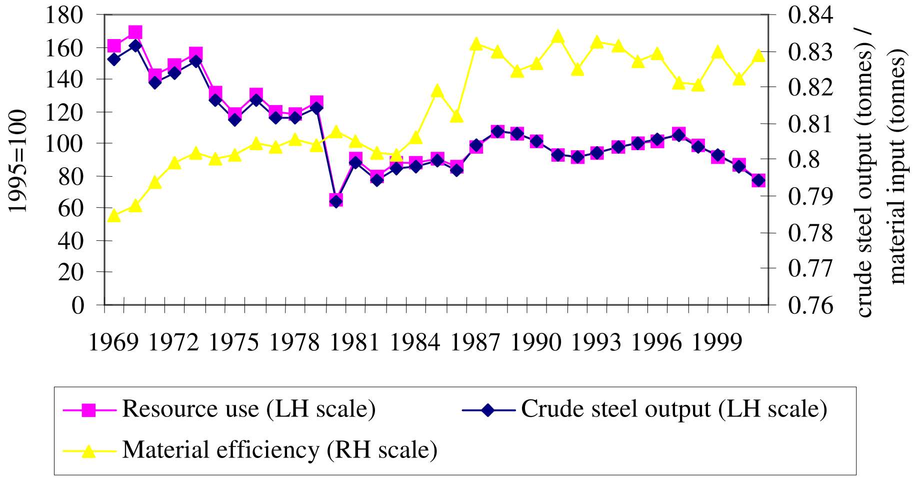

Figure 6.1 Material efficiency, UK crude steel production

The figure illustrates substantial improvements in the material efficiency of crude steel production, with the ratio approaching one. In 1969, one tonne of material inputs was needed to produce 780 kg of crude steel, whereas in 2001 the same amount of input produced 830 kg of crude steel. The efficiency improvements are associated with the gradual closure of old steelworks and their replacement with newer plant, and the take-up of continuous casting methods, which are more efficient than ingot casting.

Crude steel production in the UK has also decreased, from 26.8 Mt in 1969 to 13.5 Mt in 2001, so there has been a reduction in resource use in absolute as well as relative terms: the total inputs used in crude steel production have decreased by 50% over the time period studied, to around 16 Mt of inputs in 2001.

6.1.2 Energy efficiency

Using figures on energy consumption by the UK iron and steel industry, published by the ISSB, and the amount of total steel products produced in the UK, a measure of energy efficiency can be calculated. The steel output in tonnes is divided by the amount of energy consumed, in terajoules (TJ)[18], to get an indicator of the efficiency with which energy is used in steel production.

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[18] For the years 1968 to 1970, energy consumed was given in million therms. To convert million therms into terajoules, the DTI conversion matrix was used (available on www.dti.gov.uk/energy/inform/energy_prices/2001/september01/contents/shtml).

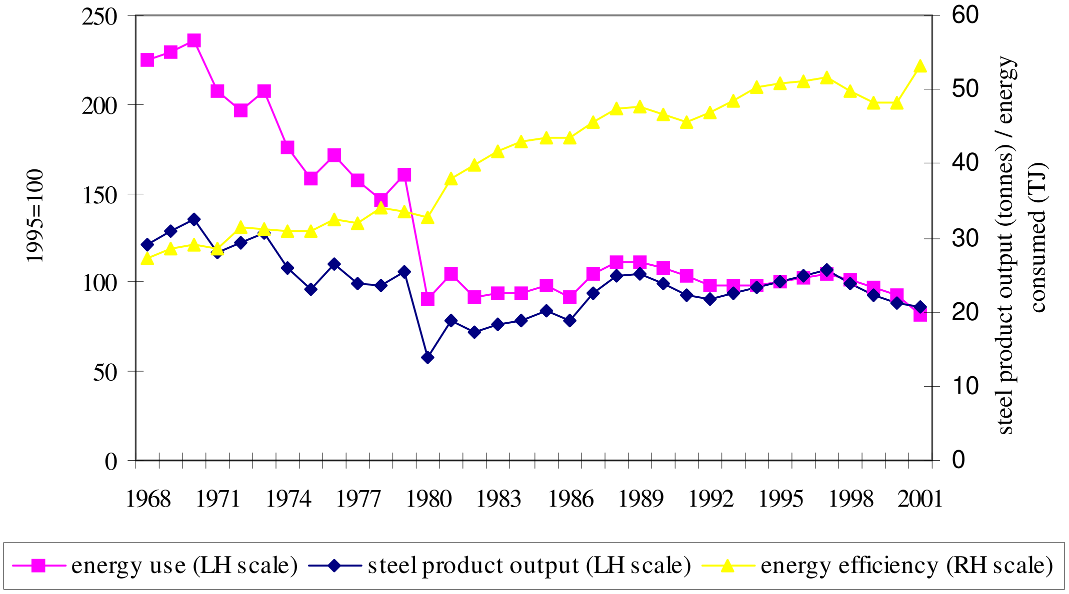

Figure 6.2 Energy efficiency in the UK iron and steel industry

As can be seen in Figure 6.2, the energy efficiency of the UK iron and steel industry has improved substantially since the 1960s. It has almost doubled: in 1968, one TJ of energy produced 27 tonnes of steel, but in 2001 the same amount of energy produced 53 tonnes of steel.

As the size of the industry has contracted in the time period studied, from an output of 19.5 Mt of steel products in 1968 to 13.8 Mt steel products in 2001, the absolute energy use has decreased by 63.5% in the time period studied, to 260,000 TJ energy consumed in 2001.

6.1.3 Resource productivity (Y_o/M_i and Y_o/E_i)

Establishing a measure of resource productivity

To establish whether the industry has decoupled economic growth from its use of nature, indicators of economic output per material and energy input need to be created. A key issue in establishing any form of resource productivity indicator concerns boundaries of economic activities. The two variables used to construct the indicator must refer to the same unit of activity, with the same boundaries, and it is important to clarify which exact parts of an industry a data set refers to. Industry definitions used must be consistent across different data sets. However, for resource productivity indicators, the physical and economic data sets invariably come from different sources, thus complicating definitions of the industry.

These issues make it difficult to establish an appropriate indicator of resource productivity, as both nominator and denominator need to refer to the same unit of production. Should such an indicator be established, the obvious fact that industries, including iron/steel, change substantially over time also reduces the accuracy of any time series of resource productivity. Table 6.1 illustrates the complexity involved in translating SIC codes between different system revisions.

Table 6.1 Iron and steel SIC codes

UK SIC(92) DESCRIPTION	SIC(92)	SIC(80)	SIC(68)
Manufacture of basic iron and steel and of ferro-alloys (ECSC)	27.10	2210	311
			313
Manufacture of cast iron tubes	27.21	3111p	311
			313
Manufacture of steel tubes	27.22	2220	312
Cold drawing	27.31	2235p	311
Cold rolling of narrow strip	27.32		399
Cold forming or folding	27.33		
Wire drawing	27.34	2234p	394
Other first processing of iron and steel not elsewhere classified; production of non-ECSC ferro-alloys	27.35	2247/1p	323
		3111p	311
			313
		3120p	321
			322
			323
			399
		3138p	399
		3204/1p	341
		3204/2p	
		3289/3p	384
Casting of iron	27.51	3111p	311
			313
Casting of steel	27.52	3111p	311
			313

It is obvious from the table that the way the iron and steel industry has been classified in various SIC revisions has changed substantially. For example, the current (SIC(92)) definition of basic ECSC iron and steel production, heading 27.1, corresponds to two different headings in the 1968 system (SIC(68)); 311 and 313. These two groups however also included activities that are now covered by SIC(92) 27.35, 27.51 and 27.52. The list in the table is also not exhaustive. For example, SIC(68) code 323 (other base metals) was replaced in 1980 (SIC(80)) by 3111, ferrous metal foundries, and 3112, non-ferrous metal foundries, which in the SIC(92) system have been split between 27.35, steel, and 27.45, other non-ferrous metal production. This means caution will have to be applied when analysing any results using time series based on these data, as trend interruptions may reflect statistical artefacts rather than real changes.

As a measure of economic output, figures on gross value added (GVA) are used. GVA for the industry comes from several different UK government publications for the period 1973[19] to 2001. Producer GVA measures the contribution to the economy of individual producers, sectors, or, as in our case, industries, and is used to estimate gross domestic product. It is essentially a measure of income minus the cost of inputs, and therefore a good measure of the value created by an industry.

Table 6.2 shows the data sources used to establish time series measures of resource productivity for the iron and steel industry, attempting to use the SIC codes available that relate as closely as possible to the ISSB definition for the iron and steel industry.

Table 6.2 Iron and steel GVA data sources

Period	Iron and Steel Industry Definition	GVA definition	Source
1974-1978	SIC (1968) Order VI, heading 311 iron and steel (general), 312 steel tubes	Gross value added at factor cost	Report on the Census of Production (1978) Summary Tables PA1002, Table 1
1979-1992	SIC (1980) 2210 iron and steel industry, 2220 steel tubes	Gross value added at factor cost	Report on the Census of Production (1982, 1987, 1992), Summary Tables PA1002, Table 11
1993-1997	SIC (1992) 27.1 manufacture of basic iron and steel and ferro-alloys, 27.22 steel tubes, 27.31 cold drawing, 27.32 cold rolling of narrow strip, 27.35 other first processing of iron and steel not elsewhere classified	Gross value added at factor cost	Production and Construction Inquiries, Summary Volume (1997), Summary Tables PA1002, Table 8
1998-2001	SIC (1992) 27.1 manufacture of basic iron and steel and ferro-alloys, 27.22 steel tubes, 27.31 cold drawing, 27.32 cold rolling of narrow strip, 27.35 other first processing of iron and steel not elsewhere classified	Approximate gross value added at basic prices	Annual Business Inquiry, Subsection DJ (released 18/06/2003)

Material productivity: Y_o/M_i

Data on material inputs in steel production is only available for crude steel production. This part of the industry broadly correlates with the basic definition of ECSC iron and steel making used in the national accounts, SIC(92) heading 27.1. Figure 6.3 shows the movement of gross value added for this group and the production of crude steel in the UK.

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[19] Before 1973, GVA is not available at the desired level of disaggregation.

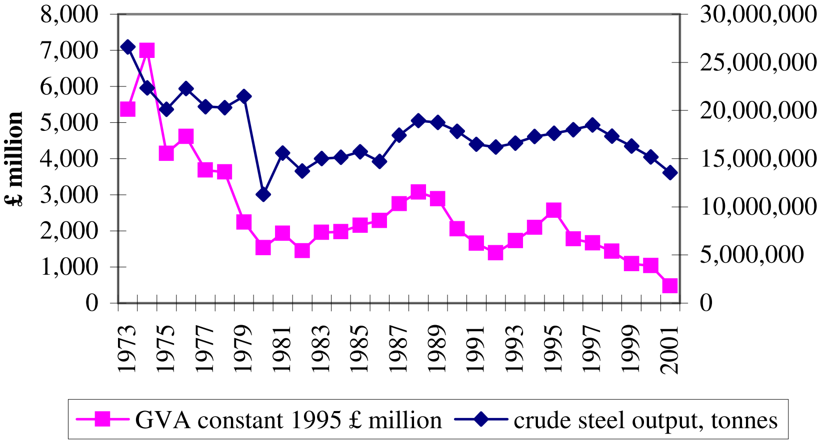

Figure 6.3 Crude steel economic and material output

While the lines increase and decrease together, the increasing gap between material and economic output represents the decline, in real terms, in the value added by this industry since the 1970s.

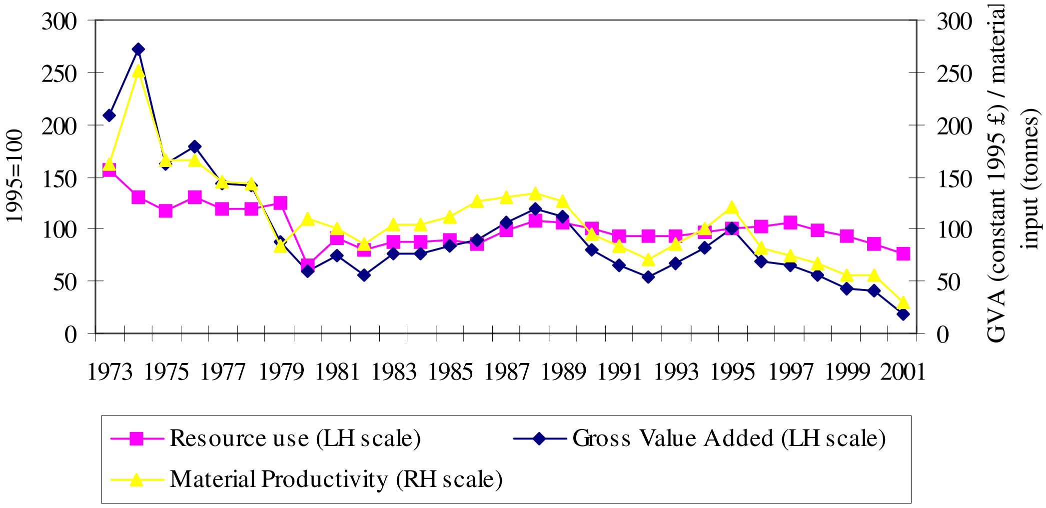

Figure 6.4 Material productivity, UK crude steel production

In contrast to the material and energy efficiency measures of productivity, which showed substantial improvements over time, the general picture here is one of rapid resource productivity decline after 1974, followed by fluctuating but gradually declining resource productivity throughout the 1980s and 1990s. In 1973, the gross value added (in constant 1995 prices) per tonne of material inputs was £162, and in 2001 the corresponding value was £29. This decline in value is true also in absolute terms: the gross value added for this part of the industry was £5.4 billion in 1973, and only £554 million in 2001.

Energy productivity: Y_o/E_i

Another important productivity measure is value added per units of energy consumed, which can be calculated for the broader industry as defined by the ISSB. The energy consumption given here would refer to the parts of the industry classified in SIC(92) as 27.1, 27.22, 27.31, 27.32 and 27.35. Figure 6.5 shows the value added, in constant terms, and the material output (steel products) of these parts of the industry, and Figure 6.6 shows the energy productivity of the industry.

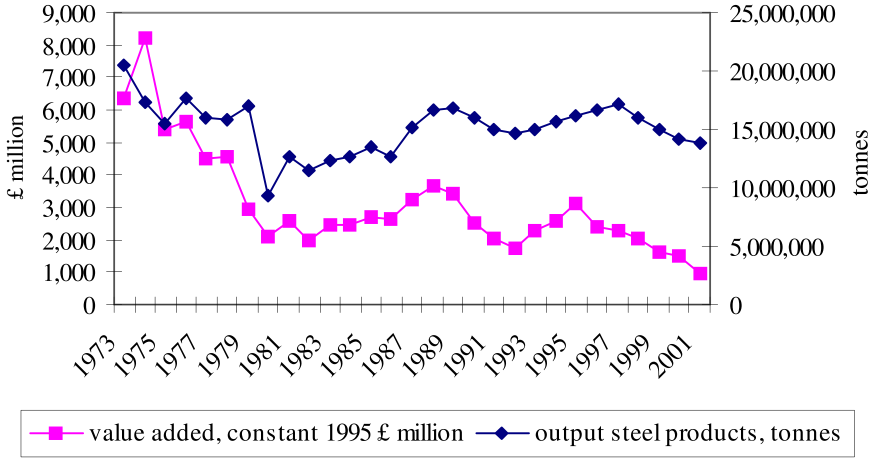

Figure 6.5 Economic and material output, UK iron and steel industry

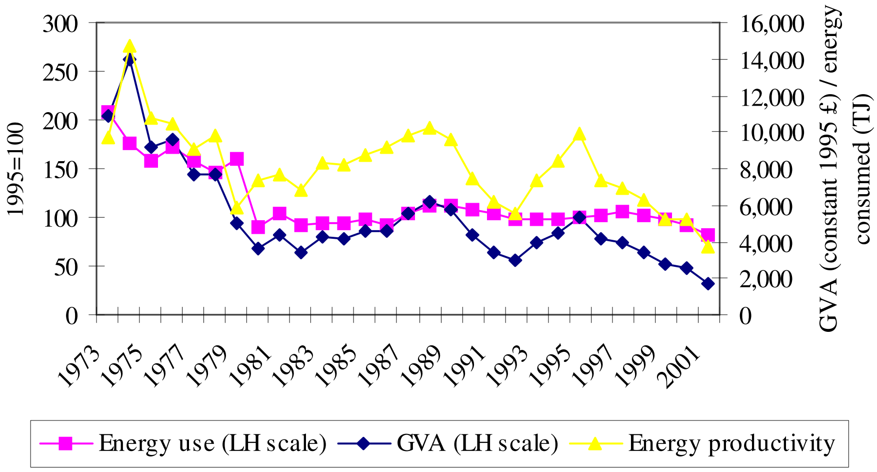

Figure 6.6 Energy productivity, UK iron and steel industry

As with Figure 6.4, this indicator also shows a decreasing trend. The value added (1995 base year) per TJ energy consumed was £9,700 in 1973, whereas in 2001 the corresponding value was only £3,800. The value has also declined in absolute terms: the total value added for this part of the industry was £6.4 billion in 1973, and £980 million in 2001.

6.1.4 Labour productivity

The resource productivity indicators above, showing the value added per different uses of nature, are thought to be analogous with labour productivity (PIU, 2001), which is a key measure of productivity used by the government. Figure 6.7 shows economic labour productivity: value added per worker, for the UK iron and steel industry (SIC 27.1). Economic labour productivity improved until the early 1990s when it started fluctuating, and has steadily declined since 1995. The rapid improvements between 1987 and 1989 are thought to be associated with high demand for steel during this time. The decline in the early 1990s is associated with the UK recession, and improvements between 1992 and 1995 are attributed to major reorganisation of the industry in 1992. The decline since 1995 is thought to be associated with the decline in production and the strength of the sterling. In 2001, the value added per worker was just over £16,000.

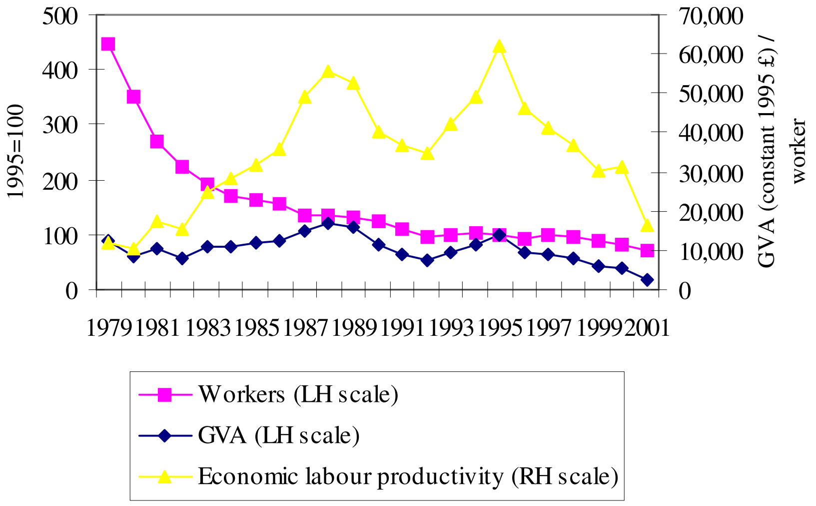

Figure 6.7 Economic labour productivity (SIC 27.1): value added per worker

The fluctuations in the measure of labour productivity are smoothed out when plotting output in material terms. Figure 6.8 shows tonnes of crude steel produced per worker. This measure shows steady improvements over the time period studied: the industry is getting better at producing steel with fewer workers. In 1979, the output per worker was 116 tonnes of crude steel, compared to 467 tonnes in 2001.

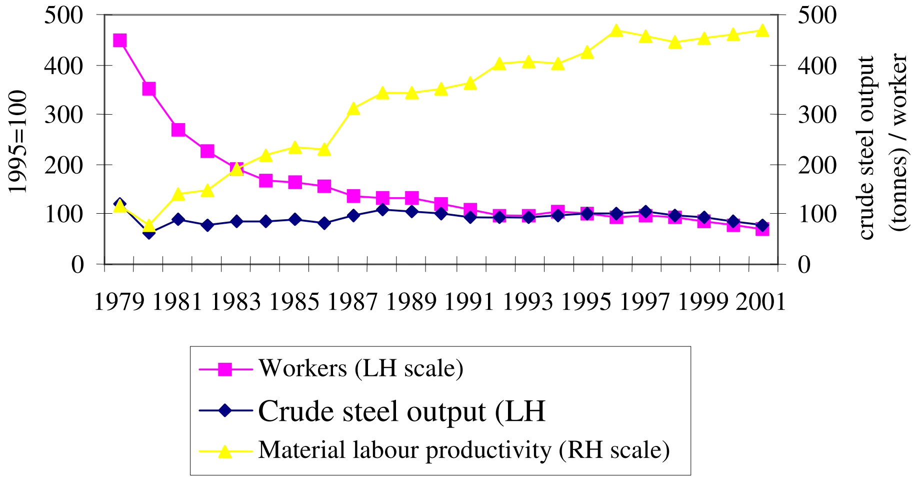

Figure 6.8 Material labour productivity (SIC27.1): crude steel output per worker

Figure 6.9 shows the crude steel output and the employment associated with this part of the industry. Employment figures have decreased dramatically. From employing 185,000 people in 1979, this part of the iron and steel industry now employs only 29,000 people – a reduction by 84%.

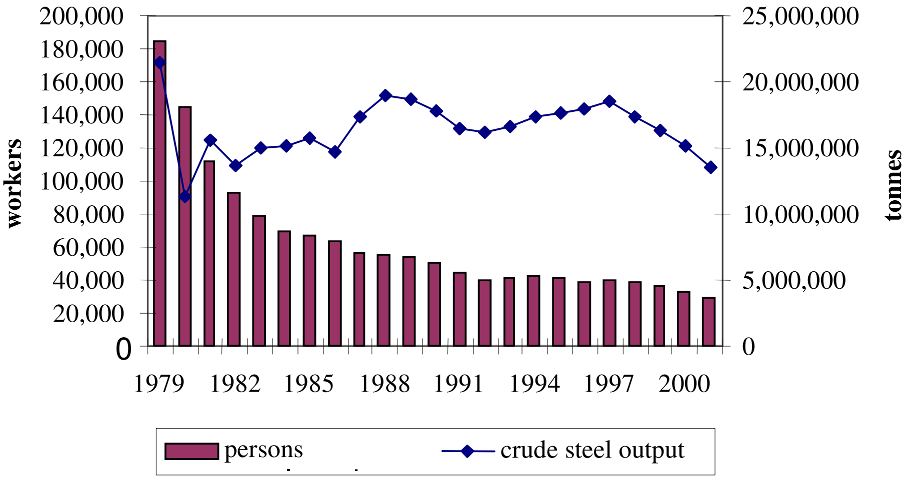

Figure 6.9 Iron and steel (SIC 27.1) output and employment

6.1.5 Resource productivity and efficiency findings

The UK iron and steel industry has over the time period studied improved the efficiency with which it uses material and energy inputs substantially. These efficiency gains are relative as well as absolute. In relative terms, fewer inputs are needed per unit of output now compared to 30 years ago. Between 1968 and 2001, the amount of crude steel produced from a tonne of material inputs increased by 6% to 830 kg, and energy efficiency almost doubled, with one TJ of energy producing 53 tonnes of steel in 2001.

These improvements are associated with the gradual modernisation of steel plants, and technological advances in casting processes and the take-up of continuous casting techniques, and improvements in stock management.

In absolute terms, there are now fewer material and energy inputs required in total by the UK iron and steel industry compared to 30 years ago. Inputs for crude steel production have decreased by 50% in the time period studied, to just over 16 Mt in 2001. Energy consumption for the iron and steel industry has decreased by 63.5%, to 260,000 TJ energy consumed in 2001. From an environmental perspective, these are positive findings, as environmental impacts depend on absolute levels of resource use.

The absolute decline in steel industry resource use is due to the contraction of the industry, the output of which has declined by 29% in the time period studied, to 13.8 Mt of steel products in 2001. It is also indicative of the broader shift in the UK away from manufacturing toward a service economy. However, as the UK's per capita steel consumption has increased, the shrinking of the UK iron and steel economy has been accompanied by a rise in imports of iron and steel, and the placing of environmental burdens outside of the country's borders.

In contrast with the resource efficiency indicators, resource productivity indicators show productivity declines over the period studied. The steel industry today generates less value per material and energy inputs compared to 30 years ago. Between 1973 and 2001, the value added (in real terms) per tonne of material inputs in crude steel production decreased by 82% to £29, and the value added per TJ of energy consumed in the iron and steel industry decreased by 61% to £3,800. The decline in value is also absolute, with the gross value added by crude steel production (SIC(92) 27.1) decreasing from £5.4 billion in 1973 to £554 million in 2001.

Economic labour productivity, measuring value added per worker, has fluctuated quite widely, with rapid productivity declines since 1995, although overall the trend seems to be moving upward. Value added per worker (in crude steel production) was just over £16,000 in 2001. However, material labour productivity shows constant improvements over the whole time period studied. Between 1979 and 2001, material output per worker increased by 75%, to 467 tonnes of crude steel output per worker in 2001. It is therefore clear that while steel production has declined in the UK, the associated employment has declined more rapidly – by 84% between 1979 and 2001, to 29,000 employees in 2001.

It is interesting that the resource productivity indicators, employing monetary output variables, demonstrate declines, whereas the resource efficiency indicators, using physical output variables, demonstrate significant improvements. What this reflects is the fact that prices of metals have fallen dramatically in real terms over the last few decades. Figure 6.10 shows the price of crude steel in constant prices between 1973 and 2001, during which time it has fallen by a factor of 4.

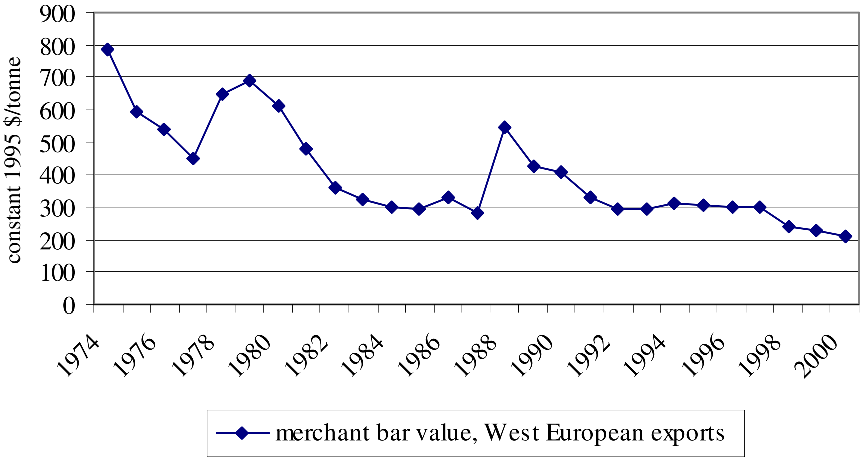

Figure 6.10 Price of Western European steel (merchant bars) exports in constant prices

Metal prices are known to be quite volatile, particularly in times of high inflation and periods of exchange rate variability. Other possible explanations for metals price volatility are speculative activity (Slade, 1991), although in the medium-term high demand is thought to have more of an impact on price volatility (Brunetti and Gilbert, 1995; Figuerola-Feretti and Gilbert, 2001). It is apparent that the price of steel can fluctuate a lot in the short term, but the long-term trend is one of falling prices.

The findings in this section raise important questions for the use of resource productivity indicators, involving monetary output measures, for examining trends relating to environmental impacts and resource use at the sectoral level. Steel products are globally traded commodities, subject to intense competitive pressures and, therefore, pressures to cut costs. Wages are a major element of costs and therefore there is a relentless drive to increase labour productivity, either by increasing output per worker, or by reducing employment while keeping output constant. It was seen above that labour productivity in both steel and aluminium has increased substantially.

However, wages are a major element of value-added as well as a major cost. If a sector's wage costs fall, permitting a fall in price, so will its value added, and this is what has happened with steel, as seen above. With sectoral resource productivity measured as sectoral value added per tonne of resources (either as input or output), sectoral resource productivity will decline. However, as seen above, this says nothing about the efficiency with which the resources have been used: the material and energy efficiency of steel production have increased substantially over the past few decades.

6.2 Mapping the value chain

Mapping the current flows of values of the materials through the UK iron and steel industry requires not only knowledge of what the material flows are – the *M* aspect of the diagram in Section 5.2.2 – but also an appreciation of the values – the *P* aspect – of the material categories.

This section will use the methodology described in Section 5.2.2 to map the current (2001) value chain associated with the UK iron and steel industry. This will identify where values accrue. The resulting value map of principal materials will then be used to examine the relationship between value, waste management regulations, and the cost of waste disposal. The relationship between the environmental impact and value of different material categories will also be examined.

6.2.1 Values of material categories

This section is concerned with the values of the principal material categories, rather than the values or costs of ancillary and energy inputs or residual outputs (for a consideration of these, see Section 6.3).

Values for the main material categories were collected from a number of different sources (Table 6.3). In general, where ranges of values were given, the most conservative value was used, unless discussions with industry indicated that this would not be appropriate. The main material categories of iron and steel are iron ore, pig iron, crude steel, iron and steel industry products, new goods containing iron and steel, and scrap. To map the value chain associated with these materials, values need to be collected from a range of different sources for these material categories, as well as for waste disposal. Values for the new goods category have not been established, as this is an immensely heterogeneous group both in terms of material composition and resulting values.

In general, it was possible to find value information for these material categories; however, these are average or representative values. Crude steel, for example, has different values depending on the quality of the material, its origins, and its destination. While the material flow analysis does not differentiate between the different forms of crude steel, for certain categories, such as crude steel and scrap, it is important to reflect the wide variations in values. Table 6.3 shows, using the nomenclature described in Section 5.2.2, the material categories used and their value data sources.

Table 6.3 Iron and steel material category value data sources

Principal Category	Detail	Abbr.	Value (£/tonne) all data 2001	Source
Iron ore	imported	1P1i	20	HMCE, SITC 281
Pig iron	domestic	1P2d	60	industry estimate
Pig iron	exported	1P2x	510	HMCE, SITC 671.2 and 671.3
Pig iron	imported	2P2i	180	HMCE, SITC 671.2 and 671.3
Crude steel	carbon steel	P3^{1}d	170	MEPS (rebar averages)
Crude steel	low alloy steel	P3^{2}d	470	HMCE, SITC 672.49
Crude steel	high alloy steel	P3^{3}d	960	MEPS (stainless steel)
Crude steel	exported	P3x	290	HMCE, SITC 672
Crude steel	imported	3P3i	310	HMCE, SITC 672
Steel products	domestic	3P4d	420	HMCE, SITC 673-679 average (includes stainless steel products)
Steel products	exported	3P4x	420	HMCE, SITC 673-679 average
Steel products	imported	4P4i	380	HMCE, SITC 673-679 average
New goods / goods in use			not applicable	
Scrap	home scrap	3P6d	90	Metalbulletin, highest new scrap price
Scrap	prompt scrap	4P6d	90	Metalbulletin, highest price (9C)
Scrap	old scrap	5P6d	50	USGS, composite No1 heavy melting scrap
Scrap	exported	P6x	80	HMCE, SITC 282
Scrap	imported	P6i	280	HMCE, SITC 282
Waste disposal	landfill	Pw	-(16) + (-12)	Hogg and Hummel, 2002; HMCE

As all iron ore for use in UK steel production is imported, the average import price of £20/tonne is taken from Customs and Excise trade statistics.

For pig iron, there are exports and imports and domestic production, so values for all these three types of pig iron need to be established. Average import and export values per tonne of material again are from trade statistics, with imports of pig iron averaging £180/tonne and exports averaging £510/tonne. It is apparent from looking at this range of values that while pig iron is a distinct material category, the form of the material – notably the size of the pellets – greatly influences the value of the product. Due to the broad price ranges, it was decided after discussions with industry that a representative value for UK domestic production of pig iron would be in the region of £60-70 per tonne. A domestic value of £60/tonne is therefore used in this value chain mapping.

Crude steel can be produced to many different specifications, and this material has therefore been divided into three generic groups: carbon steels, which are the ‘basic’ form of crude steel and used for such products as rebar; low-alloy steels, which contain small amounts of alloys; and high-alloy steels, which include stainless steels which contain high amounts of chromium, and other specialist steels that will be more expensive to produce. The average values per tonne of carbon steels, low-alloy steels and high-alloy steels are £170, £470, and £960 respectively. In addition to these values, generic values for imports and exports of crude steel are derived from Customs and Excise trade statistics. Imports of crude steel (ingots and other primary forms) averaged £310/tonne in 2001 and exports £290/tonne.

Crude steel is turned into steel products in steel mills. Steel products are a very broad category, and average UK values of these different products are not easily available. Therefore, average export values, £420/tonne, have been used also for domestic production. The average value of imports of steel products used is £380/tonne. These are high averages, as the traded steel products include smaller amounts of very valuable alloy products that increase the mean. However, as the material flow analysis does not differentiate between these different types of steel products, any further value breakdown is not meaningful.

Steel products are transformed into new goods for consumption and use by a vast range of different manufacturing processes in different sectors. From a mass balance perspective, the flux of metal to and from these sectors must be ascertained, however, from a value chain perspective the sheer amount of material combinations and ranges in values for new goods would make such an exercise futile. Also, only a part of the product value would relate to the metal content, but there is no satisfactory way of apportioning that share.

The price of iron and steel scrap depends on the composition of the scrap as well as the readiness for use as charge, which is affected by the shape, size, and level of cleanliness of the scrap. Currently, close to 30 different specifications of ferrous scrap are traded in the UK, ranging from old (end-of-life) bulky steel scrap, to compressed new, or prompt, scrap from manufacturing. However, the material flow analysis can only really differentiate between new and old scrap, so representative prices were established from the range of scrap prices available.

The value for new scrap, £90/tonne, was the highest value cited for any grade of new scrap in the 2001 Metalbulletin price data, but this was used, as the data source is known for publishing conservative estimates of scrap prices. The value for old scrap, £50/tonne, comes from data published by the United States Geological Survey, which is considered to be a reliable source of price data. Average values for imports and exports of ferrous scrap, from Customs and Excise, are £280/tonne and £80/tonne respectively.

Waste disposal costs are a combination of the fees charged by landfill site operators at the gate, and the landfill tax introduced by the UK government in 1996. The average current and likely future waste disposal charge in the UK has been estimated at £16/tonne by Hogg and Hummel (2002:38), to which the 2001 landfill tax rate of £12/tonne was added. The waste disposal cost, or negative value in value chain terms, used is therefore £28/tonne of landfilled waste.

The values for the principal material categories, as they relate to the UK domestic situation, are displayed in Figure 6.11.

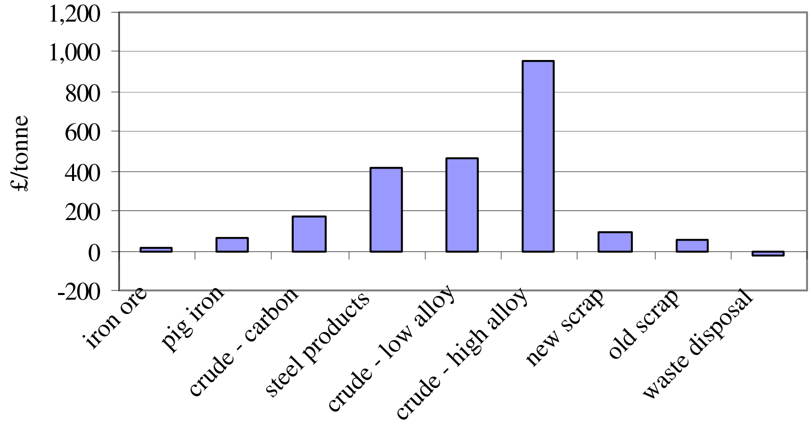

Figure 6.11 Iron and steel principal category values

6.2.2 The iron and steel value chain

Using these values in combination with the material flows collected and modelled by the project, the current UK iron and steel value chain can be mapped (Figure 6.12).

There is no longer any iron ore mined in the UK, and in 2001, the value of imports was just over £300 million. Like many other minerals, the price of iron ore has experienced a dramatic price decline in real terms. However, the very rapid growth in Chinese steel production since 2000 is currently exerting an upward pressure on iron ore prices.[20]

Imports and exports of pig iron are very small in both material and value terms, with the value of imports totalling less than £30 million and the value of exports, less than £4 million. Exports of pig iron virtually disappeared after 1995, however, 2001 saw small exports but with a very high average monetary value per tonne compared to imported pig iron. The output of pig iron for the domestic market is valued at almost £600 million.

Imports and exports of crude steel in 2001 totalled around £120 million and £220 million respectively. To estimate the values for crude steel output from the integrated route and the electric arc route, a more detailed level of breakdown on material flows than that used in the material flow analysis is necessary. Based on data on the production of alloy qualities published by the ISSB[21], the relative amounts of carbon, low-alloy, and high-alloy steels produced in the basic oxygen and electric arc furnaces respectively can be determined.

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[20] http://www.roskill.com/reports/iron

[21] ISSB (2002) table 13 shows production of alloy qualities by process (BOF or EAF), and amounts of alloys types produced are published in table 12. As a negligible amount of all alloy quality crude steel was produced by the integrated route in 2001 (0.6%), the amounts in table 12 can be taken to refer solely to EAF production. High alloy steels are defined as stainless and high speed steels, low alloy steels are the remainder, allowing these amounts to be calculated as percentages of total EAF output.

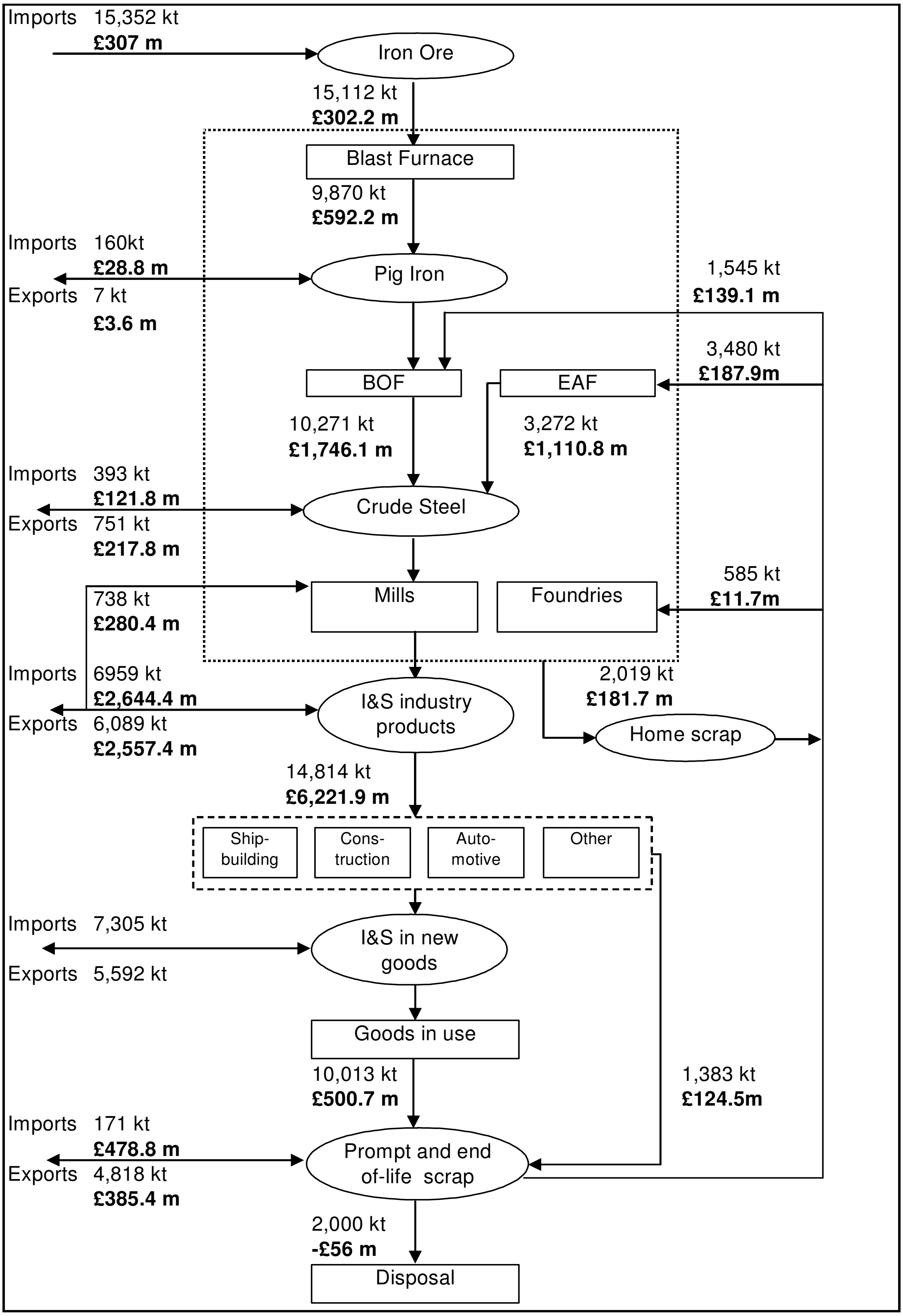

Figure 6.12 Iron and steel current industry value chain

The integrated, or BOF, route produces a negligible amount of alloy steels, so all output is assumed to be carbon steel. Using a value of £170/tonne for this material sub-category, the total output from this route is valued at £1.75 billion in 2001.

The EAFs, which use iron and steel scrap rather than iron ore as input, produce 68% carbon steels, 17% low alloy steels, and 15% high alloy steels. The high value of alloy steels compared to basic carbon steels means that while the EAF output in material terms is considerably smaller than the output from the integrated route, the difference in value is not so large. The total value output from the EAF route in 2001 was £1.11 billion.

On a pound per tonne basis, the output from the electric arc furnaces, which use predominantly old scrap as a material input, is therefore substantially higher than that from the integrated route which uses predominantly virgin inputs: an average of £340/tonne compared to £170/tonne. The very high value of the output from the EAFs is due to their focus on high alloy steels. The production of lower grade, and therefore lower value, steel products in EAFs came to a halt in 2001, but some production has recently restarted (Honess, 2004, *pers. comm.*).

UK production of steel products is worth over £6.2 billion, and the value of imports and exports are also considerable: £2.9 and £2.6 billion respectively. International competition and cheap imports help explain the rising trend in imports since the early 1990s, as well as the decline in exports in the last few years.

The large volume of end-of-life scrap arisings has a total value of about £500 million, and the smaller amount of prompt scrap arisings is valued at £125 million. Exports of scrap are growing rapidly, and represent a value of £385 million in 2001. Scrap imports are much smaller, however, due to the much higher average price paid for these materials, imports are actually worth more, £479 million, than the exports. Unfortunately, the trade statistics on scrap do not offer any detail on the types of scrap traded, but the imports are assumed to be specialty grades of high-value scraps. As UK EAF production is focused on the higher value steel grades, scrap exports are likely to be used in lower grade steel production.

Values of scrap flows entering the iron and steel production system have also been estimated. The values of the scrap inputs going into the basic oxygen furnace are calculated by assuming, based on discussions with industry, that these flows consist of 90% home scrap, which clearly has a value but is in effect not traded but internally circulated within the works, and 10% new or prompt scrap. While home scrap is not sold, the price of new scrap has been applied to it to demonstrate its value. These assumptions give a total value of the scrap going into BOF steel-making of around £140 million. The actual cost to the industry however would only be around £14 million.

Scrap inputs into electric arc furnace steel-making are assumed to consist of 10% new scrap and 90% old scrap, giving a total estimated value – or cost to the industry – of £188 million. Flows of scrap into the foundries, worth an estimated £12 million, are assumed to consist of iron scrap, which according to Metalbulletin price data has an average value of £20/tonne.

Finally, while most of the iron and steel that arises as scrap is being recovered through recycling in the UK or, as is increasingly the case, exported for recycling elsewhere, a great amount is being sent to landfill. The 2 Mt of iron and steel material contained in waste being sent to landfill in 2001 are estimated to cost £56 million. This cost falls primarily on local authorities throughout the UK, which have limited budgets. Also, waste disposal costs are increasing as the landfill tax is expected to eventually reach £35/tonne, at which level (assuming no change in gate fee) the amount of iron and steel disposed of would cost £102 million.

The materials also represent a potentially valuable source of raw materials for the iron and steel industry, and a potential income for those who could recover them. The profitability of recovery depends on many factors: the rise in landfill tax; the landfill reduction targets to which local authorities are committed; and the steel packaging recovery targets set by the packaging regulations. These will increase the extent to which scrap collection, sorting and preparation are carried out. The issues in relation to packaging are explored in some detail in Section 8. However, if the steel currently sent to landfill could be recovered and sold as old scrap at the price of £50/tonne, it would have a value of £100 million.

6.2.3 Value and environmental impact

The above section demonstrates the considerable monetary value associated with old and prompt iron and steel scrap. Steel scrap has considerable value, and steel recycling is a well-established activity for which substantial infrastructure exists. Therefore, a large proportion of steel scrap that arises in the UK is recovered, either for reprocessing in UK steelworks or, increasingly, for recycling abroad.

However, a considerable amount of scrap is disposed of as waste in landfills, at a financial cost primarily to local authorities. There are of course other non-monetary 'costs' associated with the landfilling of this material. Also, while the above section considered the values of different forms of iron and steel throughout the production and use chain, there are of course environmental impacts associated with these forms of the materials as well.

When following a specific product or product type through a supply chain, the primary stages of the chain are often responsible for significant environmental impacts, such as waste and CO_2 emissions, that are disproportionate to the associated value added by those stages (Clift and Wright, 2000). Figure 6.14 contrasts the value per tonne of material for key iron and steel categories with the CO_2 emissions associated with producing one tonne of the particular material category.

As can be seen in Figure 6.13, in relation to the value of materials, the materials associated with the early stages of the production chain – iron ore from mining, pig iron from the blast furnace, and primary steel from the integrated route have rather high emissions of greenhouse gases in relation to their value (as kg /£). Iron and steel scrap have comparatively much lower emissions in relation to the value of the material. The figure does not show greenhouse gas emissions for secondary or recycled steel, and while there can be differences in price and quality between primary and secondary steel, they are broadly comparable products even though secondary products have much lower greenhouse gas emissions per tonne of useful output. It has been estimated that producing a tonne of virgin tin plate steel emits on average 2.97 tonnes of CO_2 equivalents, but producing the same product from scrap inputs emits only around 1.16 tonnes of CO_2 equivalents (AEA Technology, 2001:180). However, no generic emissions values were obtained for secondary steel.

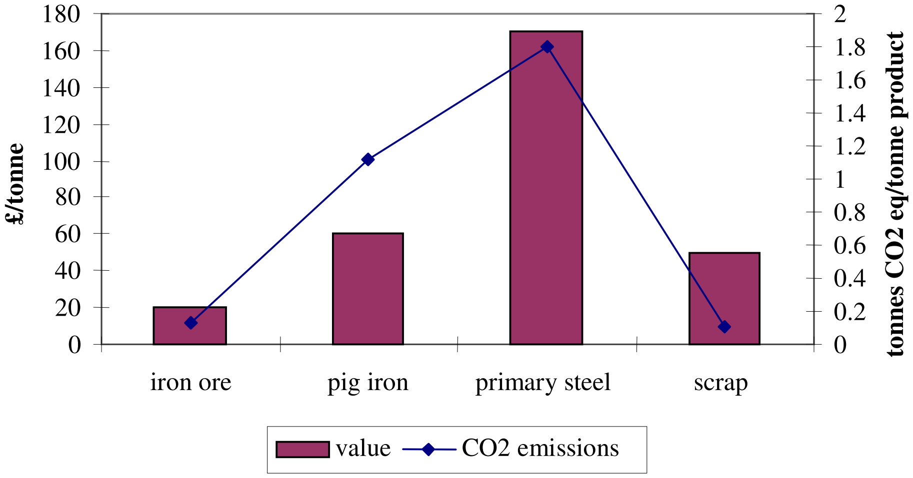

Figure 6.13 Value and CO_2 emissions per tonne of iron and steel material categories[22]

The consideration of environmental impacts in combination with economic values strengthens the case for materials recovery and reuse. Recycling of materials at the end-of-life product stages reduces not only the amount of waste that otherwise would have gone to landfill, but it also indirectly reduces the environmental impacts associated with the upstream production stages.

6.2.4 Value chain findings

The substantive value adding in the UK iron and steel production chain comes from the production of crude steel and steel products. Both these material sub-categories can vary substantially in value. Certain forms of crude steel, such as stainless or other alloy steels,

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[22] Figures on CO_2 emissions for iron ore, pig iron and primary steel from SimaPro (version 5.1) software, which include both foreground and background emissions. Scrap emissions are from Davis (2004), and are associated with emissions from collection of the material.

have a much higher value than the more basic carbon steels. These types of steels are made in the electric arc furnaces rather than in the integrated route, with associated energy and raw materials savings.

Steel products represent the final output of the iron and steel industry, and are inputs into various manufacturing sectors. Both imports and exports of steel products have increased over the last few decades. The UK currently exports a large amount of steel products, but imports more. Imports of steel products currently meet just over 50% of domestic demand. Maintaining or increasing the share of UK produced output for the domestic market has been identified as vital to the UK iron and steel industry (House of Commons, 2003).

Trade in scrap can be highly valuable: the 4.8 Mt of scrap that were exported from the UK in 2001 had a total value of around £385 million, and the 171 kt of imported scrap were worth around £379 million. However, in combination with the finding that 2 Mt of steel was disposed of to landfill in 2001, at a cost to local authorities, it seems that incentives are not high enough to encourage further recovery of this material stream.

As the cost of disposing the material as well as the value of recovering it would fall on many different and dispersed actors – local authorities and scrap collectors/reprocessors respectively – coordinated efforts to recover more scrap become more complicated. A higher degree of vertical integration, or vertical cooperation, of the iron and steel supply chain would be beneficial from a materials recovery point of view. However, as Aylen (2003) points out, key to recovering scrap is to create a demand for it, as demand finds it own supply.

6.3 Other applications of value chain analysis

In the previous section, the focus was on mapping the value chain associated with the flows of key steel materials. The focus could also be placed on costs, of all or particular inputs, or of waste disposal.

The project did not collect time series data on the inputs of ancillary materials or outputs of residual materials associated with iron and steel production. However, data on inputs of main ancillary materials into the UK iron and steel industry in 2001 (ISSB, 2002) can be combined with value data.

Figure 6.14 shows that the total value of those input materials, or their costs, depending on one's perspective, were around £450 million. Note that this figure does not represent the actual cost to the UK iron and steel industry of buying these inputs in 2001, as price ranges for the sorts of commodities needed vary hugely depending on amount purchased as well as specific quality required, however, the values can be seen as a ballpark estimate.

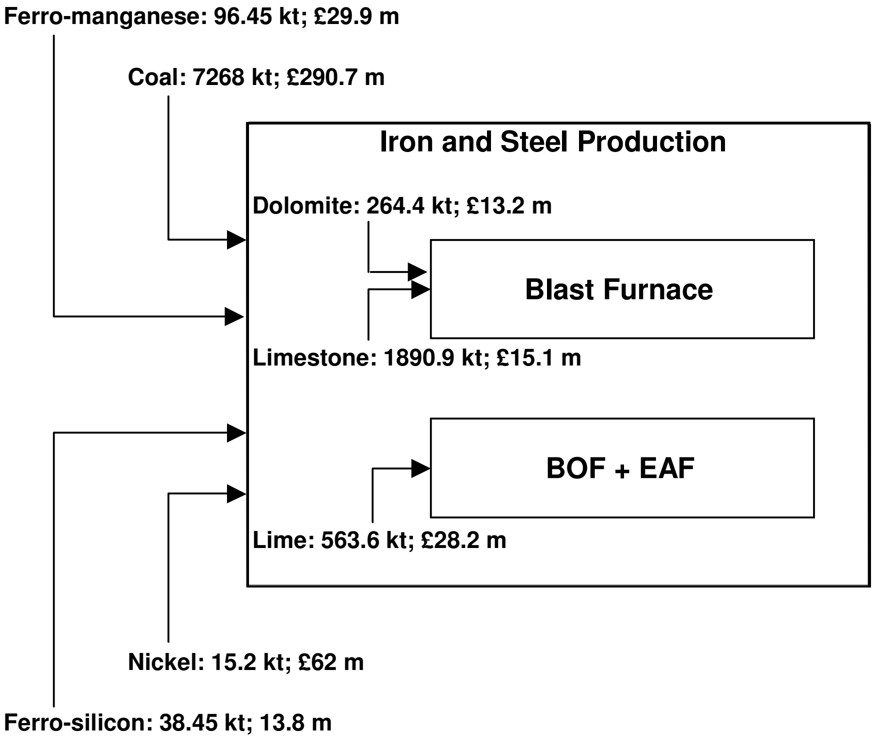

Figure 6.14 Iron and steel: Inputs of main ancillary materials and their values[23]

The potential applications of the value chain framework are limited more by data availability constraints than by other considerations. For example, the overview methodology could allow an examination of energy costs – Pe1, Pe2, etc, using the associated nomenclature described in Section 5.2.2 – to which could be added the Climate Change Levy, in order to map out the where the costs of this energy tax are the greatest, and to compare impact on primary versus secondary steel producers. However, due to the lack of transparency in the negotiated climate change agreements; the complicated system of exemptions and discounts for the levy; and the confidentiality with which industry treats its energy costs, such an examination would be very difficult to undertake from outside the industry.

However, to demonstrate the sorts of things the combined MFA-VCA could be used for, publicly available data on main inputs and outputs in key iron and steel production process steps have been combined with material and value data collected by the project, for a closer examination of the outputs of residual materials of the UK iron and steel industry, and whether these residual materials are sold as valuable by-products and therefore have positive value; whether they are reused or recycled internally, in which case they have positive value but are revenue neutral as no financial transaction takes place; or whether they have negative value because they have to be disposed of as waste.

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[23] Sources for value data are: Ferro-manganese and ferro-silicon from HMCE; nickel from LME; coal from DTI; dolomite, lime and limestone from ProdCom.

Waste disposal costs are likely to rise significantly in the UK, with landfill tax rates for active waste, currently at £14/tonne, set to increase at a rate of £3/year from 2005/6 until the medium- to long-term aim of £35/tonne is reached. Therefore, the fate of residual materials is a very policy-relevant matter. Another policy-relevant matter is the emission of greenhouse gases, particularly as the EU emissions trading directive is due to come into force in 2005. The outputs of these gases will therefore be considered as well.

6.3.1 Combining life cycle inventory data with data on material flows and values

The European Commission (2001b), publish IPPC BREF documents which detail best available techniques for various industries with regard to pollution prevention and control. The BREF on iron and steel production contains basic input-output tables for key steel-making processes. These are the production of pig iron in the blast furnace; steel-making in basic oxygen furnaces; and steel-making in electric arc furnaces; as well as the production of sinter in sinter plants and coke in the coke oven, two processes which are normally attached to the pig iron production, as sinter and coke are two key inputs into the blast furnace.

The input-output data, which show representative European values rather than UK ones, are supplemented with information on the fate of outputs, such as the average proportion of BF-slags that are sold, landfilled, and reused. The fates of the various outputs have also been discussed with the UK industry to get a more representative picture for the situation here. The input-output data is provided in a weight or energy unit per tonne of product output (i.e. pig iron in the case of the blast furnace). Combining this information with the data collected by the MFA on actual (2001) UK production of these principal materials, outputs of UK residual materials and their destinations can therefore be estimated. The cost of waste disposal and the value of finding commercial outlets for residuals can then be calculated.

6.3.2 Outputs from steel production processes

The tables below show the key material outputs, their destination, and the associated value, for the UK iron and steel industry in 2001, as well as emissions of greenhouse gases. Note that the tables are not a mass balance, but show key solid outputs and emissions of greenhouse gases only. All calculations have been made using the minimum values in the range given in the IPPC BREF, thus providing conservative estimates. All value data refer to 2001.

Table 6.5 Key outputs from the sinter plant

Sinter plant: key output 7,106,400 tonnes of sinter				
Reused residuals:	Quantity (t)	Value (£)	Value per tonne	Source / comment
dust	9,244			
sludge	3,081			
Greenhouse gases as CO_2 equivalents:				
CO_2	7,720,368			

Table 6.6 Key outputs from the coke oven plant

Coke oven plant: key output 2,763,600 tonnes of coke				
Sold residuals:	Quantity (t)	Value (£)	Value per tonne	Source / comment
benzene	22,109	£4,421,760	£200	DTI 2001 average gas oil price
tar	231	£30,043	£130	DTI 2001 average gas heavy fuel oil price
Reused residuals:				
sulphur	4,145			
sulphuric acid	11,054			
ammonium sulphate	4,698			
Greenhouse gases as CO_2 equivalents:				
CO_2	6,611,911			

Table 6.7 Key outputs from the blast furnace

Blast furnace: key output 9,870,000 tonnes of pig iron				
Sold residuals:	Quantity (t)	Value (£)	Value per tonne	Source / comment
BF slags	2,013,116	£14,091,812	£7	USGS 2001 BF slag price
Reused residuals:				
dust	66,762			
Landfilled residuals:				
BF slags	41,084	-£739,512	-£18	Gate fee of £16/tonne (Hummel and Hogg, 2001:38) plus 2001 active waste tax rate of £12/tonne or inactive waste tax of £2/tonne
rubble	143,794	-£2,588,292	-£18	
sludge	30,813	-£862,764	-£28	
Greenhouse gases as CO_2 equivalents:				
CO_2	10,544,893			

Table 6.8 Key outputs from the basic oxygen furnace and casting

Basic oxygen furnace: key output 10,271,000 tonnes of crude steel				
Sold residuals:	Quantity (t)	Value (£)	Value per tonne	Source / comment
slag	191,677	£958,387	£5	USGS 2001 BOF slag price
Reused residuals:				
slag	277,461			
dust	13,558			
mill scale	8,217			
spittings	12,325			
Landfilled residuals:				
slag	260,904	-£4,696,271	-£18	Gate fee of £16/tonne (Hummel and Hogg, 2001:38) plus 2001 active waste tax rate of £12/tonne or inactive waste tax of £2/tonne
dust	1,849	-£51,766	-£28	
rubble	8,217	-£147,902	-£18	
Greenhouse gases as CO_2 equivalents:				
CO_2	421,796			

Table 6.9 Key outputs from the electric arc furnace

Electric arc furnace: key output 3,272,000 tonnes of crude steel				
Sold residuals:	Quantity (t)	Value (£)	Value per tonne	Source / comment
slag	83,898	£419,492	£5	USGS 2001 BOF slag price
Reused residuals:				
slag	60,881			
Landfilled residuals:				
slag	253,653	-£4,565,759	-£18	Gate fee of £16/tonne (Hummel and Hogg, 2001:38) plus 2001 active waste tax rate of £12/tonne or inactive waste tax of £2/tonne
dust	32,720	-£916,160	-£28	
refractory bricks	6,544	-£183,232	-£28	
Greenhouse gases as CO_2 equivalents:				
CO_2				data not provided

6.3.3 Residual material findings

Table 6.10 summarises the estimated values and costs of sold and landfilled residual materials respectively for the different stages in the iron and steel production chain. The table also displays the estimated CO_2 emissions for the different stages.

While the figures are based on crude calculations, the resulting values can be used as ballpark estimates. Using this framework, the calculations indicate that the value to the UK iron and steel industry of selling residual materials is almost £20 million. Most of this value comes from the large volumes of slag that are generated from pig iron production in the blast furnace, and which can be sold as a raw material for cement manufacturing at about £7/tonne. A substantial proportion of this value is also from the sale of benzene and tar which come from the coke oven plants and which have a high value. From the basic oxygen and electric arc furnaces, there are some sales of slag for use as road stone or aggregate.

Landfilling costs for the industry are rather high, almost £15 million, however, as a large proportion of these wastes are classified as inert, even with an increase in the landfill tax rate to £35/tonne for active waste, the overall cost of waste disposal would rise by a relatively small amount, to around £16.6 million. Steel production in the electric arc furnaces has the highest amount of waste disposal costs, primarily from the generation of large amounts of slag not all of which can be sold or reused. Landfill costs are also high for residual outputs from the basic oxygen and blast furnaces, and are made up mainly of slag and other solid wastes.

Table 6.10 Iron and steel: summary of residual material values

Process	Principal output (t)	Sold residuals	Landfilled residuals	CO2 (t)	CO2 / Principal output (t)
Sinter Plant (sinter)	7,106,400			7,720,368	1.09
Coke Oven Plant (coke)	2,763,600	4,451,803		6,611,911	2.39
Blast Furnace (pig iron)	9,870,000	14,091,812	-4,190,568	10,544,893	1.07
Basic Oxygen Furnace (crude steel)	10,271,000	958,387	-4,895,939	421,796	0.04
Electric Arc Furnace (crude steel)	3,272,000	419,492	-5,665,151	not available	
Total		**£19,921,493**	**-£14,751,658**	**25,298,968**	

The industry also generates large amounts of greenhouse gases, according to these calculations over 25 Mt of CO_2 equivalents. The majority of these are from the blast furnace, but the sinter and coke oven plants also give rise great amounts of greenhouse gas emissions. However, the input and output data in the IPPC BREF do not provide figures for CO_2 emissions from the electric route.

Also, the estimates for emissions for the different processes derived from the IPPC data are also rather different from other estimates of CO_2 emissions. For example, the emissions from crude steel production in the basic oxygen furnace are much lower than the estimated emissions for primary steel production obtained in LCA software (SimaPro). This is partly because the IPPC data gave a wide range of values, of which the lowest was used, and partly due to the unclear definition of boundaries. The resulting CO_2 emissions data in Table 6.10 should therefore be treated with much caution. Nevertheless, the estimates derived from the IPPC data are very close to the official government figures for CO_2 emissions from the UK iron and steel industry in 2001 (ENDS, 2003).[24]

While this combined material and value framework is very much a work under development, which uses average European data on outputs and their destinations, it demonstrates the potential for an analysis of this kind to pinpoint where there are particular gains to be made from waste disposal reductions and greenhouse gas emissions. This analysis would be much enhanced if using actual UK industry input-output data and their actual disposal costs and gains from sales of valuable by-products, rather than the average data and generic values used here. In terms of policy-relevant action, the framework also facilitates a consideration of key actors in an industry and the ownership structures – for example, the number of processing plants, and the level of vertical

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[24] ENDS (2003:45) quotes CO_2 emissions from the steel industry in 2001 as 7.0 tonnes of carbon, which is equivalent to (7*44/12) 25.7 tonnes of CO_2.

integration at various stages. This sort of information could be mapped onto the overview diagram of the industry.

6.4 Iron and steel value chain analysis: Summary table

Table 6.11 summarises the value chain findings described above. Data on CO_2 emissions were unavailable for all processes, or not considered robust or sufficiently transparent to estimate emissions associated with the various material categories.

Table 6.11 Iron and steel summary table

		Domestic production		Imports		Exports		Net Imports = Imports - Exports	
Material category		Weight (kt)	Value (million)	Weight (kt)	Value (million)	Weight (kt)	Value (million)	Weight (kt)	Value (million)
Iron ore				15,112	£302.2			15,112	£302.2
Pig iron		9,870	£592.2	160	£28.8	7	£3.6	153	£25.2
Crude steel	BOF	10,271	£1,746.1	393	£121.8	751	£217.8	-358	-£96.0
	EAF	3,272	£1,110.8						
Steel products		14,814	£6,221.9	7,697	£2,924.8	6,089	£2,557.4	1,608	£367.4
Scrap	new	1,383	£124.5	171	£478.8	4,818	£385.4	-4,647	£93.4
	old	10,013	£500.7						
Scrap to landfill		2,000	-£56.0						

The final column displays net imports (imports – exports) in both weight and value terms for the different iron and steel material categories. In weight terms, there was a trade surplus (exports exceed imports) for crude steel and scrap, however, in value terms, there was a trade surplus only for crude steel, due to the very high value of scrap imports.

7 ALUMINIUM VALUE CHAIN ANALYSIS

7.1 Aluminium resource productivity

This section examines resource productivity and efficiency trends in the aluminium industry, using both time series data on material and energy inputs and outputs for measures of material and energy efficiency, and time series data on material and energy flows in combination with data on economic output to create measures of material and energy productivity.

The analysis sheds light on broad resource productivity trends in the industry over the last two to three decades. Specifically, it has attempted to answer the following questions:

- Is the aluminium industry improving its material efficiency (M_o/M_i), that is, is it creating more useful output with fewer material inputs;
- Is the aluminium industry improving its energy efficiency, that is, is it creating more useful output with less use of energy (M_o/E_i);
- Is the aluminium industry improving its material productivity, that is, is it creating more value with fewer material inputs (Y_o/M_i);
- Is the aluminium industry improving its energy productivity, that is, is it creating more value with less use of energy (Y_o/E_i); and
- Is any observed decoupling relative or absolute?

7.1.1 Material efficiency (M_o/M_i)

As mentioned in Section 5.2.1, one of the key issues in establishing resource efficiency and productivity measures is data availability, as not all businesses or industries collect mass data on the sorts of variables one might wish to examine, over the time periods one might wish to study.

Unfortunately, data on inputs consumed in mass terms are not available for any parts of the UK aluminium industry, so no resource productivity measure of this kind can be established. However, the basic formula for primary aluminium production, in which one tonne of primary aluminium production requires two tonnes of alumina, which in turn requires four to five tonnes of bauxite, is fixed by stoichiometry, so primary material efficiency gains must therefore be negligible.

7.1.2 Energy efficiency

Energy efficiency is a key issue in aluminium production, due to its intensive energy requirements. No data are available on actual energy consumption for UK aluminium production. Therefore, energy consumption in the UK aluminium industry is estimated using average European energy consumption values. Average energy consumption values for primary production are available from the International Aluminium Institute[25], and average energy consumption values for secondary production are from the OEA and Alfed.[26] These average consumption values were combined with data on primary and secondary aluminium production to estimate total energy consumption.

Energy efficiency for primary aluminium production

Figure 7.1 shows the estimated energy efficiency of primary aluminium production based on the average European energy consumption values. There have been gradual improvements in energy efficiency over the last two decades, with one terajoule (TJ) of energy producing 16.6 tonnes of primary aluminium in 1980, whereas in 2001 the same amount of energy produced 18.2 tonnes of energy. As primary aluminium production has decreased slightly, by 9%, in the time period analysed, the relative improvement has been accompanied by an absolute reduction in energy consumption, by about 17% to 19,000 TJ energy consumed in 2001.

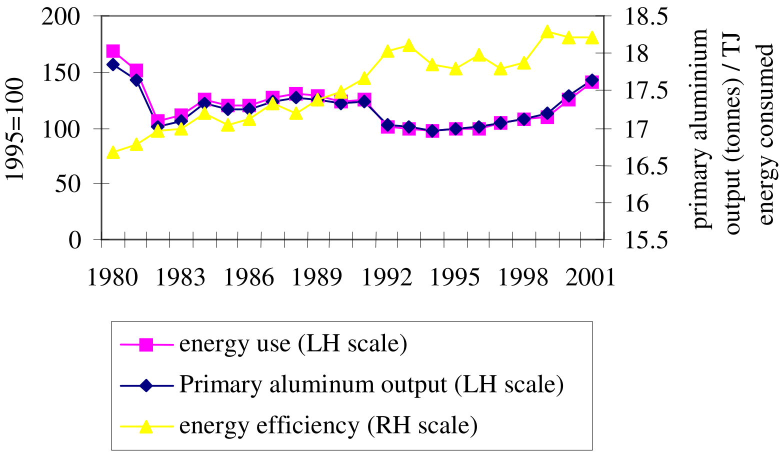

Figure 7.1 Energy efficiency, primary aluminium production

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[25] http://www.world-aluminium.org/iai/stats/index.asp, using a conversion rate of 1 kWh = 3.6 MJ.

[26] Data from 1980 to 1989 comes from OEA, data from 1990, 1995, 1998, 1999 and 2002 from Alfed. Figures for the years 1991-1994, 1996-1997, and 2000-2001 have been interpolated from the available data.

However, production has been growing rapidly since 1995 and the improvement in energy efficiency appears to have slowed, so that it seems unlikely that relative energy efficiency improvements will keep pace with the growth in output.

Energy efficiency for secondary aluminium production

Energy efficiency for the UK secondary aluminium production can be measured as a ratio of the output of secondary aluminium (produced by refiners and remelters) and the energy inputs required for this production. However, Alfed data on secondary production only goes back to 1988, and the energy consumption is based on the average European values mentioned above. As can be seen in Figure 7.2, the trend in energy efficiency over the relatively short time period for which data are available seems to be improving.

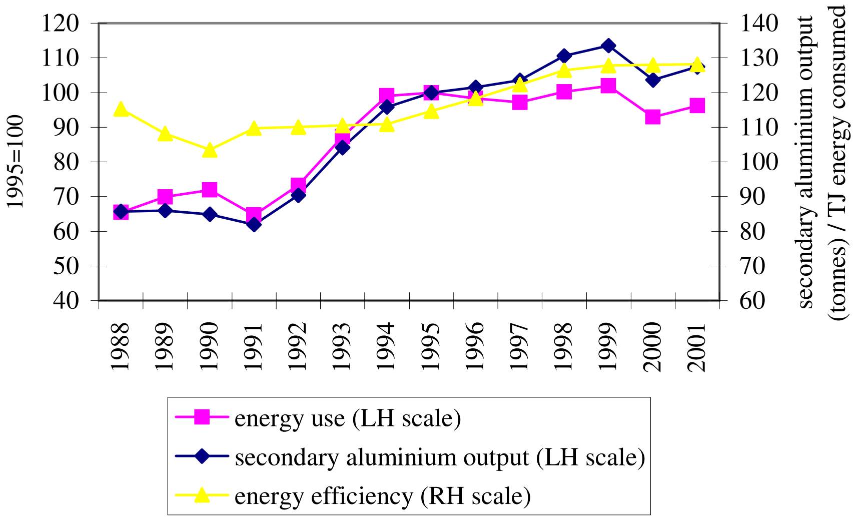

Figure 7.2 Energy efficiency, secondary aluminium production

In 1988, one terajoule (TJ) energy produced 115 tonnes of secondary aluminium output, and the same amount of energy produced 128 tonnes of aluminium in 2001. However, as secondary output has increased in the time period concerned, by a hefty 63%, total energy consumption for this part of the industry has increased by 47%, to 6,500 TJ energy consumed in 2001.

Energy efficiency: combined primary and secondary aluminium production

Figure 7.3 shows the energy efficiency of the UK aluminium industry as a whole, combining primary and secondary production and energy use.

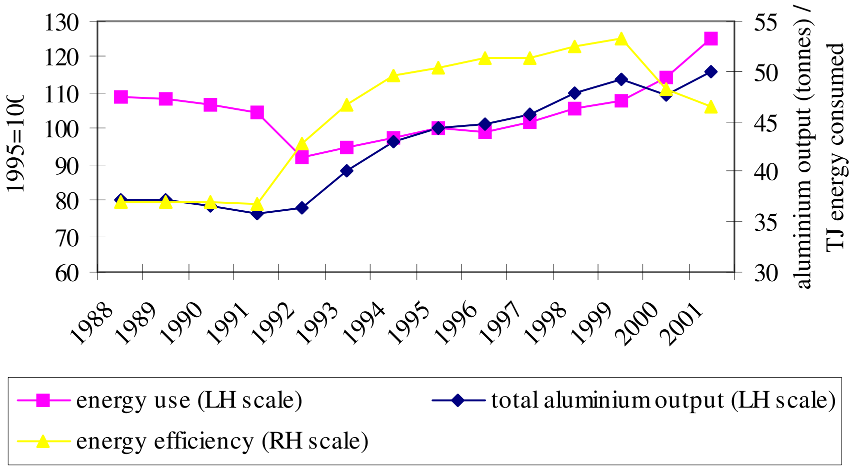

Figure 7.3 Energy efficiency, UK aluminium industry

In 1988, one terajoule (TJ) energy produced 37 tonnes of (primary and secondary) aluminium, whereas in 2001 the same amount of energy produced 46 tonnes of aluminium. However, as total output of aluminium increased by 45% to almost 1.2 Mt, total energy consumption has also risen despite the efficiency gain, by 15%, to 25,000 TJ energy consumed in 2001.

What Figures 7.1 and 7.2 show in addition to the fact that there have been improvements in energy efficiency associated with both primary and secondary aluminium production, is that the amount of energy required for primary production is much greater than that required for secondary production, about seven times as much per tonne in 2001 according to the data analysed. Therefore, the energy efficiency as well as the absolute energy consumption of the UK aluminium industry as a whole is hugely sensitive to the mix of primary and secondary production.

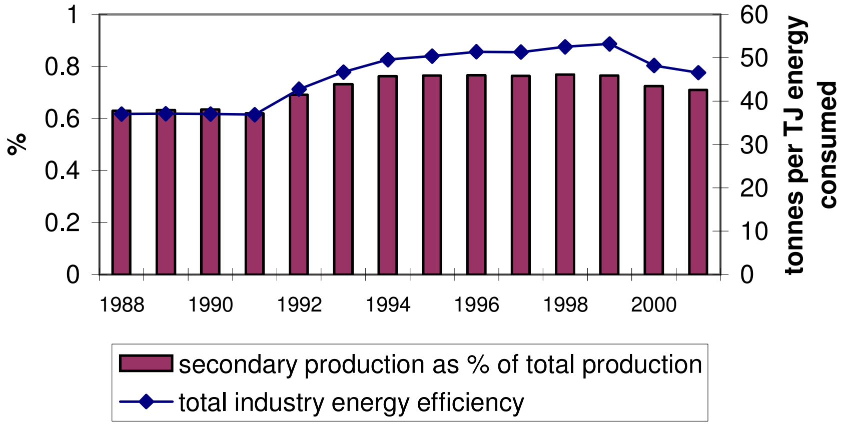

Figure 7.4 Energy efficiency and share of secondary aluminium production

Figure 7.4 shows the energy efficiency of the whole UK aluminium industry as well as the share of secondary production, using data on output from refiners, remelters and primary smelters from Alfed annual statistics. This shows how increases as well as decreases in the proportion of secondary aluminium production are followed by increases and decreases also in the energy efficiency of UK aluminium production as a whole.

7.1.3 Resource productivity (Y_o/M_i and E_o/M_i)

Establishing a measure of resource productivity

To establish whether the industry has decoupled economic growth from its use of nature, indicators of economic output per material or energy input need to be created. A key issue in establishing any form of resource productivity indicator concerns boundaries of economic activities. The two variables used to construct the indicator must refer to the same unit of activity, with the same boundaries, and it is important to clarify which exact parts of an industry a data set refers to. Industry definitions used must be consistent across different data sets. However, for resource productivity indicators, the physical and economic data sets invariably come from different sources, thus complicating definitions of the industry.

These issues make it difficult to establish appropriate indicators of resource productivity, as both nominator and denominator need to refer to the same unit of production. Should such an indicator be established, the obvious fact that industries, including aluminium, change substantially over time also reduces the accuracy of any time series of resource productivity. Table 7.1 illustrates the complexity involved in translating SIC codes between system revisions.

Table 7.1 Aluminium SIC Codes

UK SIC(92) DESCRIPTION	SIC(92)	SIC(80)	SIC(68)
Aluminium production	27.42	2245/1	321
		2245/2p	394
		2511p	271
		3164/4p	321
			395
			399
Casting of light metals	27.53	3112p	321
			322
Casting of other non-ferrous metals	27.54		323
			399

It is obvious from the table that the way the aluminium industry has been classified in various SIC revisions has changed substantially. For example, the current (SIC(92)) definition of aluminium production, heading 27.42, corresponds to four different headings in the 1980 system (SIC(80)): 2245/1, 2245/2p, 2511 p, and 3164/4p. These groups however also included activities that are now covered by SIC(92) 24.12-24.15, 24.30, 28.72 and 28.73. The list in the table is also not exhaustive. For example, SIC(68) code 323 (other base metals) was replaced in 1980 (SIC(80)) by 3111, ferrous metal foundries, and 3112, non-ferrous metal foundries, which in the SIC(92) system have been split between 27.35, steel, and 27.45, other non-ferrous metal production. This means caution will have to be applied when analysing any results using time series based on these data, as trend interruptions may reflect statistical artefacts rather than real changes.

As a measure of economic output, figures on gross value added (GVA) are used. GVA for the industry comes from several different UK government publications for the period 1973[27] to 2001. GVA measures the contribution to the economy of individual producers, sectors, or, as in our case, industries, and is used to estimate gross domestic product. It is essentially a measure of income minus the cost of inputs, and therefore a good measure of the value created by an industry.

Table 7.2 shows the data sources used to establish time series measures of resource productivity for the aluminium industry.

Table 7.2 Aluminium GVA data sources

Period	Aluminium Industry Definition	GVA definition	Source
1973-1978	SIC (1968) Order VI, heading 321: Aluminium and aluminium alloys	Gross value added at factor cost	Report on the Census of Production (1973, 1978) Summary Tables PA1002, Table 1
1979-1992	SIC (1980) 2245 Aluminium and aluminium alloys: primary and secondary aluminium and	Gross value added at factor cost	Report on the Census of Production (1982, 1987, 1992), Summary Tables

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[27] Before 1973, GVA is not available at the desired level of disaggregation.

	aluminium alloys, rolled, drawn, extruded and other semi-manufactured aluminium products		PA1002, Table 11
1993-1997	SIC (1992) 27.42 Aluminium production: includes aluminium from alumina, from aluminium waste and scrap, aluminium alloys and semi-manufacturing of alloys	Gross value added at factor cost	Production and Construction Inquiries, Summary Volume (1997), Summary Tables PA1002, Table 8
1998-2001	SIC (1992) 27.42 Aluminium production: includes aluminium from alumina, from aluminium waste and scrap, aluminium alloys and semi-manufacturing of alloys	Approximate gross value added at basic prices	Annual Business Inquiry, Subsection DJ (released 18/06/2003)

The UK aluminium industry is made up of a wide range of different operations and processes – primary smelting, refining and remelting, semi-fabrication – which all come under the same heading in the current system of industrial classifications (SIC(92)). It is believed that this economic definition of the industry corresponds well with the industry definitions used by CES in its collection of data on total material output (tonnages of semi-finished products produced in the UK).

Material productivity: Y_o/M_i

Figure 7.5 shows the economic and material outputs of the aluminium industry between 1973 and 2001. While the lines increase and decrease together, with the exception of one year, the increasing gap between material and economic output represents the decline, in real terms, in the value added by this industry since the 1970s.

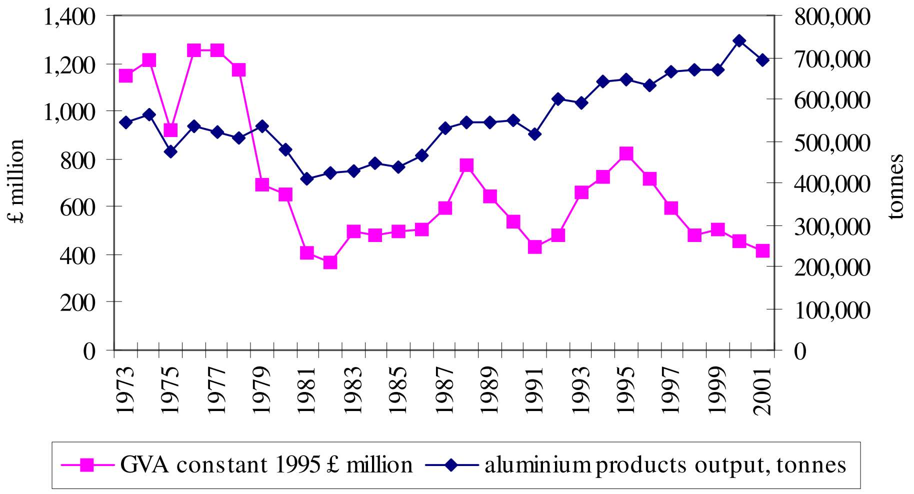

Figure 7.5 Aluminium: economic and material output

The value added by the industry shows, in real terms, wide fluctuations in a downward trend. The massive decrease in value between 1978 and 1979 is likely to be a result of the transition from the 1968 to the 1980 revision of the SIC system, which appears to have narrowed the industry in ways that have not been reflected in the way data on material output have been collated. However, the fluctuations after 1979 seem to reflect actual output volumes as well as aluminium price fluctuations and decline rather than changes in statistical boundaries. Because of this, the analysis combining material or energy and value data should start after 1979.

As mentioned in Section 7.1.1, data on inputs consumed in mass terms are not available for any parts of the UK aluminium industry, so a material productivity indicator measuring economic output per material inputs cannot be established. However, as the basic formula for primary aluminium production is fixed by stoichiometry, economic output per unit of material output can be used to formulate a proxy indicator, for purposes of trend illustration.

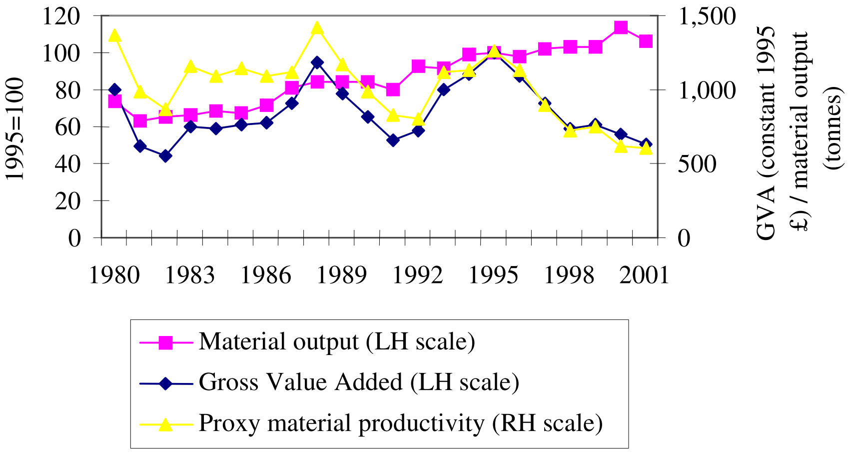

Figure 7.6 Proxy material productivity, UK aluminium production

Figure 7.6 shows the material productivity trend fluctuating substantially in a gradual downward trend. Less value is added per tonne of aluminium semis and castings produced now compared to 1980: in 1980, the value added in real terms per tonne of aluminium output was £1,365, but in 2001 this had declined by 56% to £600. The decline in value has also been absolute: the gross value added for the aluminium industry decreased by 46% between 1980 and 2001, to £416 million in 2001.

Energy productivity: Y_o/E_i

An energy productivity indicator can be established by examining value added for the industry per unit of energy inputs, using the figures for average European energy consumption described in Section 7.1.3. However, the energy consumption refers to primary smelting and refining/remelting only, whereas the data on economic output also includes the value of semifabrication and casting. Unfortunately, no further disaggregation of the value data is possible.

For purposes of illustration only, Figure 7.7 shows the value added (whole industry) per unit of energy consumed (primary and secondary aluminium production), for the UK aluminium industry between 1988 and 2001. These discrepancies in boundaries between the economic and physical data sets mean that the value per unit of energy input is exaggerated, but the broad movement of the trend should be reasonably representative. As can be seen in the figure, the trend in energy productivity is one of steady decline since 1995.

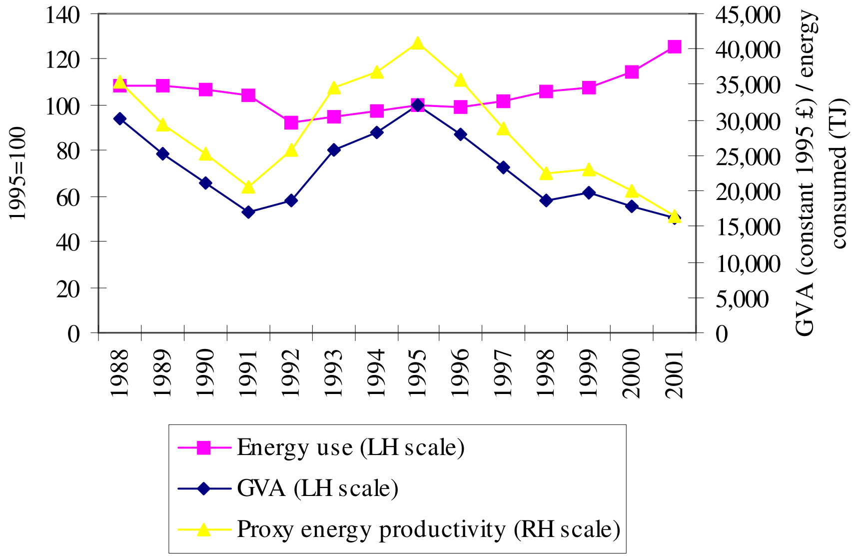

Figure 7.7 Proxy energy productivity, UK aluminium industry

7.1.4 Labour Productivity

The resource productivity indicator above, showing the value added per different uses of nature, are thought to be analogous with labour productivity (PIU, 2001), which is a key measure of productivity used by the government. Figure 7.8 shows economic labour productivity; value added per worker, for the UK aluminium industry (SIC 27.42). Economic labour productivity improved until the late 1980s and early 1990s when it declined, due to the UK recession. Economic labour productivity then improved between 1992 and 1995since when it has declined somewhat. This decline is thought to be associated with the strength of the sterling. Overall though, the trend seems to be moving upwards. In 2001, the value added per worker was about £35,000.

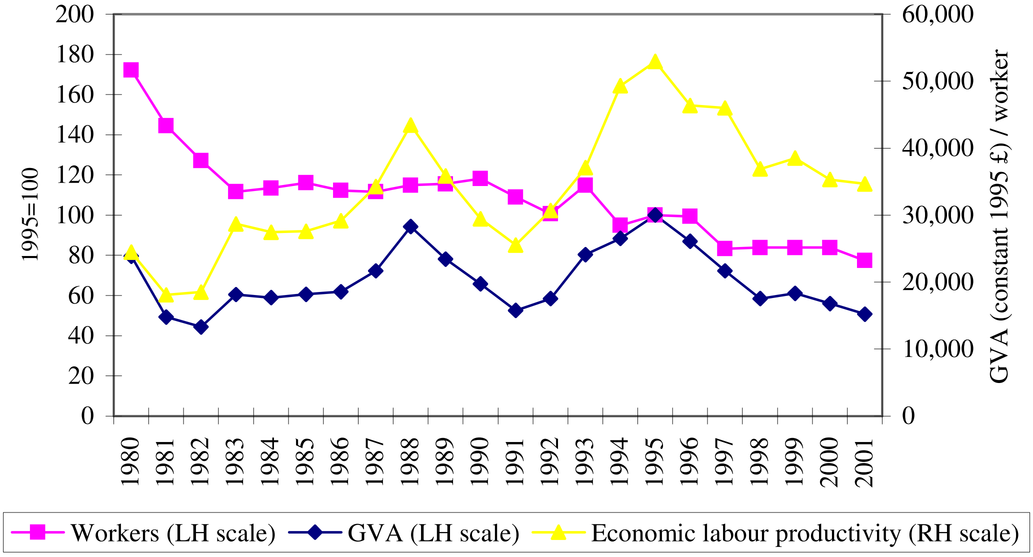

Figure 7.8 Economic labour productivity (SIC 27.42): value added per worker

The fluctuations in the measure of economic labour productivity are smoothed out when measuring labour productivity in terms of output of aluminium products per worker; material labour productivity. Figure 7.9 shows tonnes of aluminium semis and castings produced per worker. This measure shows dramatic improvements over the time period studied: between 1980 and 2001 material output per worker almost tripled, from 20 tonnes in 1980 to 58 tonnes of output per worker in 2001.

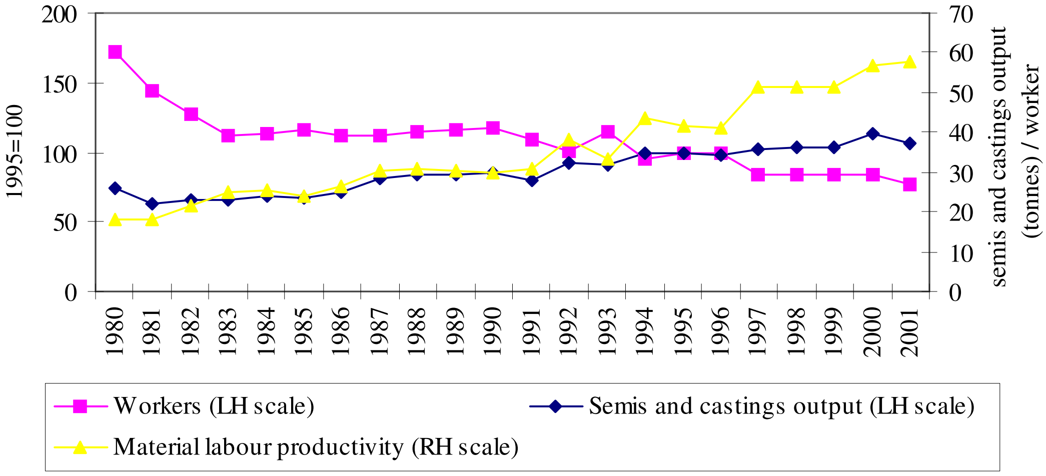

Figure 7.9 Material labour productivity (SIC 27.42): semis and castings output per worker

Figure 7.10 shows the output from aluminium semifabrication and casting and the employment associated with this part of the industry. Not only has output more than doubled, to 690 kt, but employment figures have also decreased substantially. From employing 27,000 people in 1980, the aluminium industry now employs 12,000 people – a reduction by 56%. The industry is getting significantly better at producing more aluminium with fewer workers.

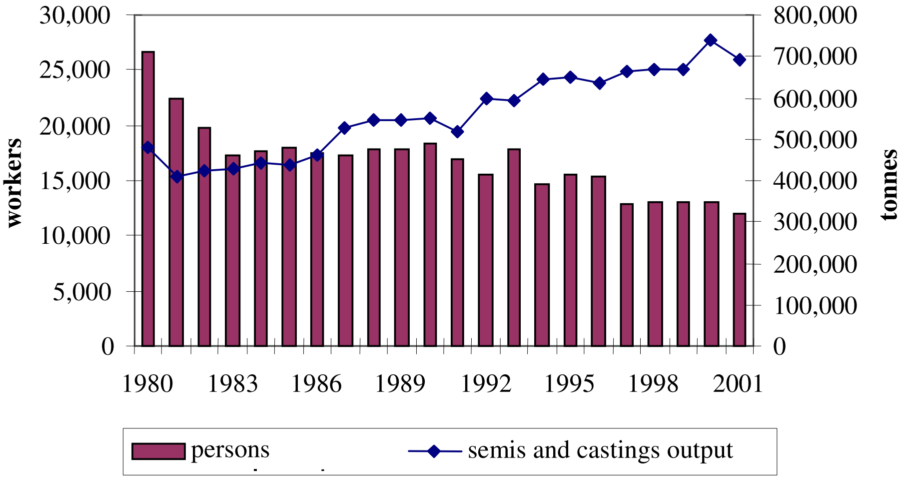

Figure 7.10 Aluminium output and employment

7.1.5 Resource productivity and efficiency findings

Due to the lack of actual data on materials and energy consumption in UK aluminium production, clear resource efficiency trends are hard to establish and results should be treated with caution. No data exist on material inputs into aluminium production, other than the basic formula used to convert bauxite into primary aluminium which is fixed. Therefore, material efficiency gains must be negligible.

Energy efficiency indicators were established with European average energy consumption figures for primary and secondary (refining and remelting) aluminium production, rather than with data on actual UK energy consumption. However, the results should give a good indication of broad trends in the industry. For primary aluminium, energy efficiency improved by 10% between 1980 and 2001, so that one TJ of energy produced 18.2 tonnes of primary aluminium in 2001. In the same time period, there has been a decline in output by 9%, to 340,800 tonnes of primary aluminium produced in 2001. Because of the efficiency gain and this decline in output, absolute energy consumption in primary production has decreased by 17% to 19,000 TJ energy consumed in 2001. However, production has been growing rapidly since 1995 and it seems unlikely that relative energy efficiency gains will keep pace with the growth in output.

The efficiency with which energy is used in secondary aluminium production has also improved. Energy efficiency improved by 11% between 1988 and 2001, to produce 128 tonnes per TJ energy consumed in 2001. However, production has grown significantly in this time period, by 63%, and the energy efficiency gains have therefore been insufficiently large to offset this growth. There has therefore been a net increase in energy use, by 47% to a total of 6,500 TJ energy consumed in 2001.

For aluminium production as a whole, combining primary and secondary aluminium production, there have been overall efficiency gains, which have been offset by the growth in total output and energy use has therefore increased between 1988 and 2001. Energy efficiency increased by 47% to produce 46 tonnes of aluminium per TJ energy consumed in 2001. As output grew by 45% to almost 1.2 Mt, total energy consumption was up 15% to 25,000 TJ energy consumed in 2001.

This analysis demonstrates the sensitivity of the industry, in terms of levels of energy efficiency and absolute energy use, to the relative proportions of primary and secondary aluminium production. Primary smelting uses about seven times as much energy as refining and remelting activities, according to the data analysed. The significant improvements in energy efficiency are positive, as is the growth in the industry, however, the total increase in energy consumption is less desirable from an environmental point of view.

In contrast with the energy efficiency indicators, resource productivity indicators show productivity declines over the period studied. It was not possible to create a material productivity indicator of the form value added per unit of material input for the aluminium industry, as no data on materials consumed were available. Data on outputs of semis and castings were therefore used to formulate a proxy material productivity indicator. This indicator showed wide fluctuations in what appeared to be a downward trend: the value added in real terms per tonne of aluminium output has decreased by 56% to £600 in 2001. Despite growth in output, this decline in value added by the industry is true also in absolute terms: the value added by the UK aluminium industry has decreased by 46%, to £416 million, between 1980 and 2001.

It was also not possible to create an energy productivity indicator for the aluminium industry, as the data on value added and the data on energy consumption referred to different parts of the industry. The energy consumption data refer to primary and secondary aluminium only, and exclude semifabrication and casting activities. However, the value of semifabrication and casting is included in the economic data. A proxy energy productivity indicator was constructed for purposes of broad trend illustration. This indicator shows steady decline in value added per unit of energy consumed since 1995.

Economic labour productivity, measuring value added per worker, has fluctuated quite widely, in what appears to be a gradual upward trend. Value added per worker was about £35,000 in 2001. However, material labour productivity shows constant and dramatic improvements over the whole time period studied. Between 1980 and 2001, material output per worker almost tripled, to 58 tonnes of aluminium products per worker in 2001.

Even though UK production of aluminium semis and castings has more than doubled between 1980 and 2001, the associated employment has declined by 56% in the same time period, to 12,000 employees in 2001.

It is interesting that the resource productivity indicators, employing monetary output variables, demonstrate declines, whereas the resource efficiency indicators, using physical output variables, demonstrate significant improvements. What this reflects is the fact that prices of metals have fallen substantially in real terms over the last few decades. Figure 7.11 shows the price of aluminium in constant prices between 1973 and 2001, during which time it has almost halved.[28]

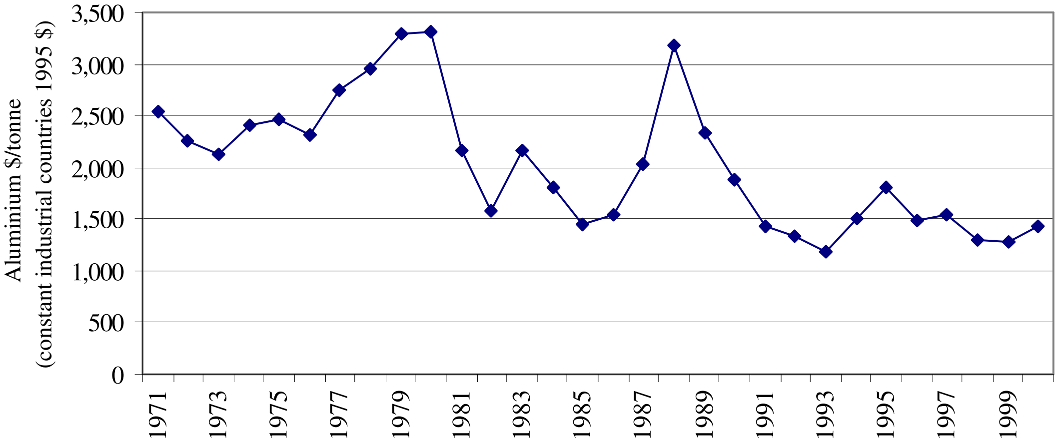

Figure 7.11 Price of aluminium

It is apparent that the price of aluminium can fluctuate a lot in the short term, but the long-term trend is one of falling prices. Metal prices are known to be quite volatile, particularly in times of high inflation and periods of exchange rate variability. Other possible explanations for metals price volatility are speculative activity (Slade, 1991), although in the medium-term high demand is thought to have more of an impact on price volatility (Brunetti and Gilbert, 1995; Figuerola-Feretti and Gilbert, 2001).

Constant price figures express value using the average prices of a selected base year, 1995 in our case. As inflation is therefore removed from the price figures, time series use constant prices. Even though the value added figures were recalculated as constant prices, using the UK GDP deflator[29] (IMF, 2002), this reflects the movement in prices of UK inputs into the economy, and aluminium is only a very small proportion of those inputs.

The findings in this section raise important questions for the use of resource productivity indicators, involving monetary output measures, for examining trends relating to environmental impacts and resource use at the sectoral level. Aluminium products are

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[28] The price series for aluminium (from IMF, 2002) was recalculated as constant prices using the industrialised countries' deflator (IMF, 2002).

[29] The price series aluminium (from IMF, 2002) was recalculated as constant prices using the world deflator (IMF, 2002).

globally traded commodities, subject to intense competitive pressures and, therefore, pressures to cut costs. Wages are a major element of costs and therefore there is a relentless drive to increase labour productivity, either by increasing output per worker, or by reducing employment while keeping output constant. It was seen above that labour productivity in the aluminium industry has increased substantially.

However, wages are a major element of value-added as well as a major cost. If a sector's wage costs fall, permitting a fall in price, so will its value added, and this is what has happened with aluminium, as seen above. With sectoral resource productivity measured as sectoral value added per tonne of resources (either as input or output), sectoral resource productivity will decline. However, as seen above, this says nothing about the efficiency with which the resources have been used: the energy efficiency of both primary and secondary aluminium production has increased substantially over the past few decades.

7.2 Value Chain Mapping

Mapping the current flows of values of the materials through the UK aluminium industry requires not only knowledge of what the material flows are – the *M* aspect of the diagram in Section 5.2.2 – but also an appreciation of the values – the *P* aspect – of the material categories.

This section will use the methodology described in Section 5.2.2 to map the current (2001) value chain associated with the UK iron and steel industry. This will identify where values accrue. The resulting value map of principal materials will then be used to examine the relationship between value, waste management regulations, and the cost of waste disposal. The relationship between the environmental impact and value of different materials will also be examined.

7.2.1 Values of material categories

This section is concerned with the values of the principal material categories, rather than the values/costs of ancillary and energy inputs or residual outputs (for a consideration of these, see Section 7.3).

Values for the main material categories were collected from a number of different sources (Table 7.3). In general, where ranges of values were given, the most representative value was established through discussions with industry. The main material categories of aluminium are bauxite, alumina, unwrought aluminium, semifabricated products, new goods containing aluminium, and scrap. To map the value chain associated with these materials, values need to be collected from a range of different sources for these material categories, as well as for waste disposal. Values for the new goods category have not been established, as this is an immensely heterogeneous group both in terms of material composition and resulting values.

In general, it was possible to find value information for these material categories, however, these are average or representative values. Semis and castings, for example, is a heterogeneous group of products the values of which vary widely depending on exact material composition, shape, and method of production. While the MFA does not need to differentiate between these different forms of semifabricated products, it is important to reflect the wide variations in values. Table 7.3 shows, using the nomenclature described in Section 5.2.2, the material categories used and their value data sources.

Table 7.3 Aluminium material category value data sources

Principal Category	**Detail**	**Abbr.**	**Value (£/tonne)** all data 2001	**Source**
Bauxite	imported	1P1i	50	HMCE, SITC 285.1
Alumina	imported	2P2i	180	HMCE, SITC 285.2
Aluminium	domestic	2P3d	1010	LME, 3-month cash mean
Aluminium (remelter's ingot)	domestic	8P3d	1010	LME, 3-month cash mean
Aluminium (refiner's ingot – high-grade)	domestic	7P3^{1}d	1150	Metalbulletin, LM 6
Aluminium (refiner's ingot – low-grade)	domestic	7P3^{2}d	920	Metalbulletin, LM 24
Aluminium	exported	P3x	1110	HMCE, SITC 684.1
Aluminium	imported	P3i	1100	HMCE, SITC 684.1
Semifabricated products (rolled sheet)	domestic	3P4^{1}d	1970	ProdCom, PCC 27422430
Semifabricated products (rolled foil)	domestic	3P4^{2}d	3120	ProdCom, PCC 27422500
Semifabricated products (extruded product)	domestic	3P4^{3}d	1750	ProdCom broad range, industry estimate of most representative
Semifabricated products (castings)	domestic	3P4^{4}d	4820	ProdCom, PCC 27531090 NB: very high
Semifabricated products	exported	3P4x	1760	HMCE, SITC 684.2
Semifabricated products	imported	4P4i	1920	HMCE, SITC 684.2
Scrap	prompt scrap	4P6d	920	OEA, new pure aluminium cuttings
Scrap	old scrap	5P6d	650	OEA, old cast scrap prices
Scrap	exported	P6x	700	HMCE, SITC 288.23
Scrap	imported	P6i	670	HMCE, SITC 288.23
Waste disposal	landfill	Pw	(-16)+(-12)	Hogg and Hummel, 2002; HMCE

All bauxite for use in the UK is imported, so the Customs and Excise average import value of £50/tonne can be used to establish the value of this material category. While there has been no smelter-grade alumina production in the UK since 2000, and therefore no bauxite imports for this purpose, the value of bauxite is displayed for information purposes. As there is no production of alumina in the UK, all of it is imported, and trade statistics suggest a value of £180/tonne for this material.

Aluminium is imported, exported and produced domestically, so values for these three types of aluminium need to be established. Average import and export values per tonne of material are £1100 and £1110 respectively according to trade statistics, and the value used for domestic aluminium is the London Metal Exchange (LME) 2001 average of £1010/tonne of material. In addition to these three sub-categories of the material, aluminium is also produced by remelters, which use predominantly new scrap as an input, and refiners, which use mainly old scrap as an input. The LME value of £1010/tonne is used for remelters' ingot, as the quality is comparable to that of primary ingots produced in primary smelters. Refiners' ingot can be broadly divided into high grade or low-grade ingot, with high grade ingot having a higher silicon content. The value used for high-grade refiners' ingot is £1150/tonne, and for low grade refiners' ingot £920/tonne.

Semifabrication of aluminium produces a range of rolled, extruded, and cast products. The differences in values between different types of these products can be very high. Average values of these types of products are not readily available, and from a value chain perspective it makes more sense to speak of representative values for representative material types within this category. Key products here are rolled sheet, £1970/tonne, rolled foil, £3120/tonne, extruded product, £1750/tonne, and castings, £4820/tonne. The values are based on available value data from the European survey of manufactured products, ProdCom. For castings, ProdCom only had data on one type with a very high value, most likely a highly specialised product. However, in absence of other readily available value data this figure is used even though it is likely to lead to an exaggeration of the value of cast products. Imports and exports of semis and castings have average values of £1920/tonne and £1760/tonne respectively according to Customs and Excise data.

Semifabricated aluminium products are transformed into new goods for consumption and use by a vast range of different manufacturing processes in different sectors. From a mass balance perspective, the flux of metal to and from these sectors must be ascertained, however, from a value chain perspective the sheer amount of material combinations and ranges in values for new goods would make such an exercise futile. Also, only a part of the product value would relate to the metal content, but there is no satisfactory way of apportioning that share.

The price of aluminium scrap depends on the composition of the scrap as well as its readiness for use as charge, which is affected by the shape, size, and the level of cleanliness of the scrap. Currently, there are 12 different specification of aluminium scrap, ranging from old scrap in the form of used beverage cans (UBCs), an important category currently worth around £700/tonne, to new clean scrap of one alloy. There is also a European standard being prepared for aluminium scrap, detailing 15 different broad categories of scrap. However, the material flow analysis can only really differentiate between new and old scrap, so representative prices were established from the range of scrap prices available.

The representative value chosen for new or prompt scrap is £920/tonne, and for old scrap it is £650/tonne. Average values for imported and exported aluminium scrap are £670/tonne and £700/tonne respectively.

Waste disposal costs are a combination of the fees charged by landfill site operators at the gate, and the landfill tax introduced by the UK government in 1996. The average current and likely future waste disposal charge in the UK has been estimated at £16/tonne by Hogg and Hummel (2002:38), to which the 2001 landfill tax rate of £12/tonne was added. The waste disposal cost (or negative value in value chain terms) used in the analysis is therefore £28/tonne of landfilled waste.

The values for the principal material categories, as they relate to the UK domestic situation, are displayed in Figure 7.12. However, as mentioned above, the value for castings is thought to be exaggerated but is used in the absence of other value data for this sub-category.

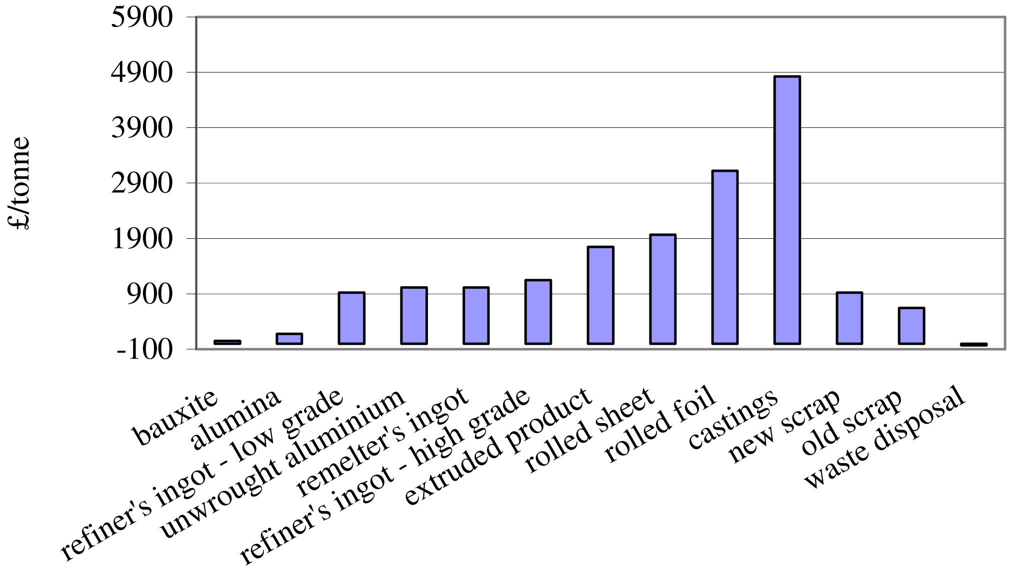

Figure 7.12 Aluminium principal category values

7.2.2 The aluminium value chain

Using these values in combination with the material flows collected and modelled by the project, the current (2001) UK aluminium value chain can be mapped (Figure 7.13).

The total value of bauxite imports in 2001 was just over £8 million, and the value of alumina imports nearly £127 million.

Imports and exports of aluminium in 2001 totalled around £380 million and £290 million respectively. Data on the output of aluminium from primary and secondary smelters are available for 2001. To estimate the value of this output, this information needs to be complemented by a breakdown of refiners' output into high-grade and low-grade ingot. Based on data from and discussions with industry, refiners are assumed to produce 40% high-grade and 60% low-grade ingot. These figures value the output of primary ingot at £344 million, of refiners' ingot at £252 million, and of remelters' ingot at £591 million – or a total of almost £1.2 billion. Remelter's ingot is usually not sold but internally transferred, although the value is displayed for purposes of illustration.

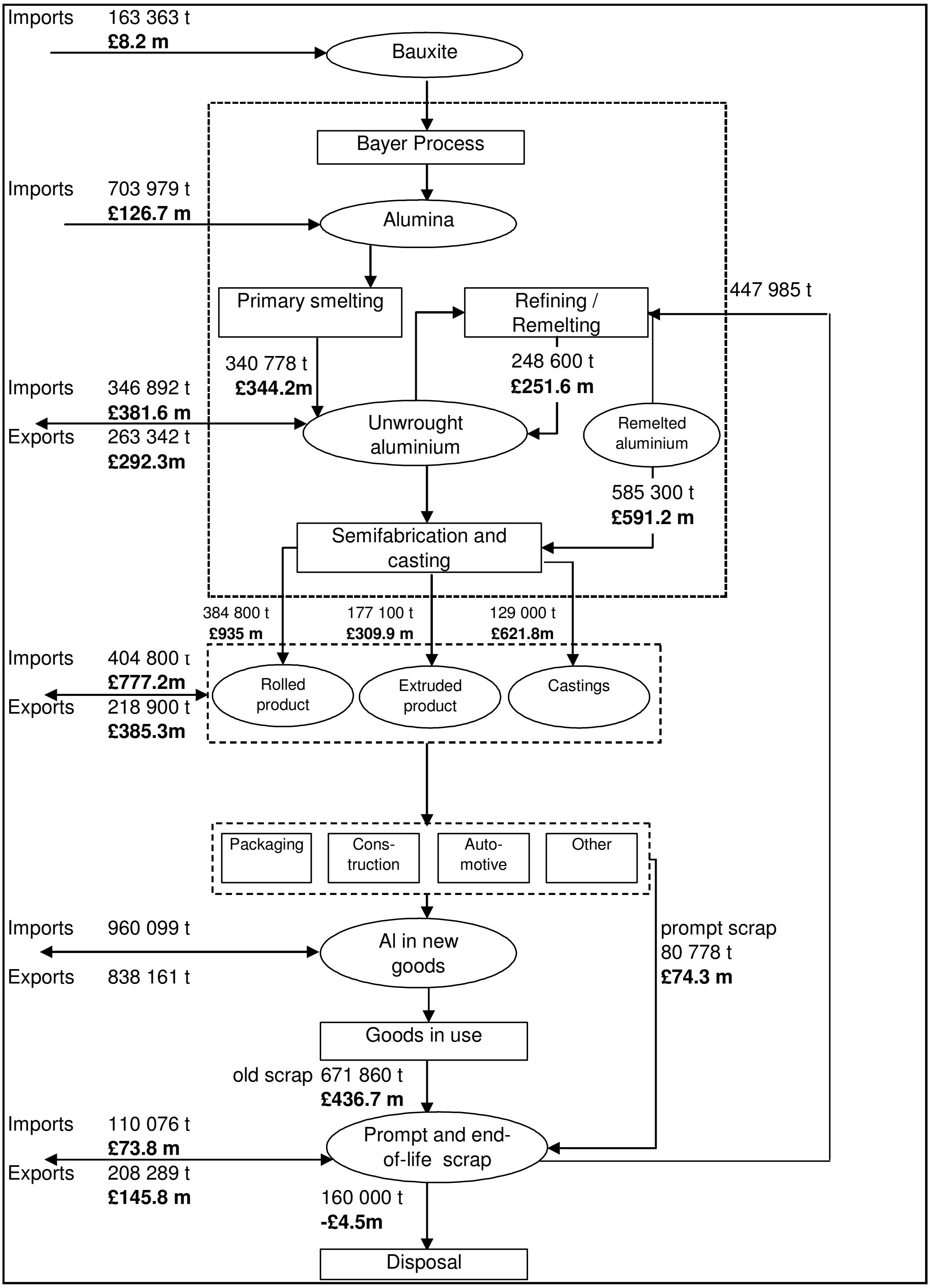

Figure 7.13 Aluminium current industry value chain

The value of the trade in semifabricated aluminium products is considerable, with imports worth £777 million and exports £385 million. The value of the domestic production of semis and castings is estimated at almost £1.9 billion. Rolled products, assuming a 40-60 per cent split between rolled foil and rolled sheet, have an estimated value of around £935 million; extruded products a value of around £310 million; and castings are estimated at around £622 million. This latter figure however is thought to be exaggerated due to the high pound per tonne value used for this material sub-category. Still, the production of semis and castings is a very high value adding activity, the demand for which is increasingly met through imports. In 2001, imports met 46% of domestic demand (production + imports – exports) in material terms, but only 34% in value terms.

The large volume of end-of-life scrap, almost 700,000 tonnes, and the high value of aluminium scrap, means that there is significant value even at this stage of the chain – almost £440 million worth of old scrap arises from the consumption and use stage. Another £74 million worth of new scrap arises from the various aluminium consuming manufacturing sectors. Scrap imports in 2001 were worth around £74 million, and exports totalled around £146 million. Imports of aluminium scrap have increased substantially since the early 1990s, coinciding with the opening of the Alcan recycling plant in Warrington. However, exports have also increased greatly over the last two decades, and while these exports represent significant value as export earnings, the outflows of these materials from the UK also represent a loss of the energy that is embodied in the scrap as well, obviously, as the materials themselves.

Finally, while most of the aluminium that arises as scrap is being recovered through recycling in the UK or, as is increasingly the case, exported for recycling elsewhere, a lot is still being sent to landfill. About 160,000 tonnes of aluminium contained in waste was sent to landfill in 2001, at an estimated cost of £4.5 million. This cost falls primarily on local authorities across the UK, which have very restricted budgets. Also, waste disposal costs are increasing as the landfill tax is expected to eventually reach £35/tonne of landfilled waste, at which level (assuming no change in gate fee) the amount of aluminium disposed of would cost over £8 million.

The aluminium sent to landfill also represents a potentially very valuable source of raw materials for the aluminium industry, and a potential income for those who could recover them. The profitability of recovery depends on many factors, the rise in landfill tax; the landfill reduction targets to which local authorities are committed; and the aluminium packaging recovery targets set by the packaging regulations. These will increase the extent to which scrap collection, sorting and preparation are carried out. The issues in relation to packaging are explored in some detail in Section 8. However, if the aluminium currently sent to landfill could be recovered and sold as old scrap at the price of £650/tonne, it would have a value of £104 million.

7.2.3 Value and environmental impact

The above section demonstrates the considerable monetary value associated with old and prompt aluminium scrap. The high value of this material and the fact that aluminium can be recycled without any loss of quality means that a lot of the scrap is recovered and recycled by the UK aluminium industry or exported for overseas recycling.

However, a considerable amount of aluminium is disposed of as waste in landfills, at a financial cost to primarily local authorities. There are of course other non-monetary ‘costs’ associated with the landfilling of this material. Also, while the above section considered the values of different forms of aluminium throughout the production and use chain, there are of course environmental impacts associated with these forms of aluminium as well.

When following a specific product or product type through a supply chain, the primary stages of the chain are often responsible for significant environmental impacts, such as waste and CO_2 emissions, that are disproportionate to the associated value added by those stages (Clift and Wright, 2000). Figure 7.14 contrasts the value per tonne of material for key aluminium categories with the CO_2 emissions associated with producing one tonne of the particular material category.

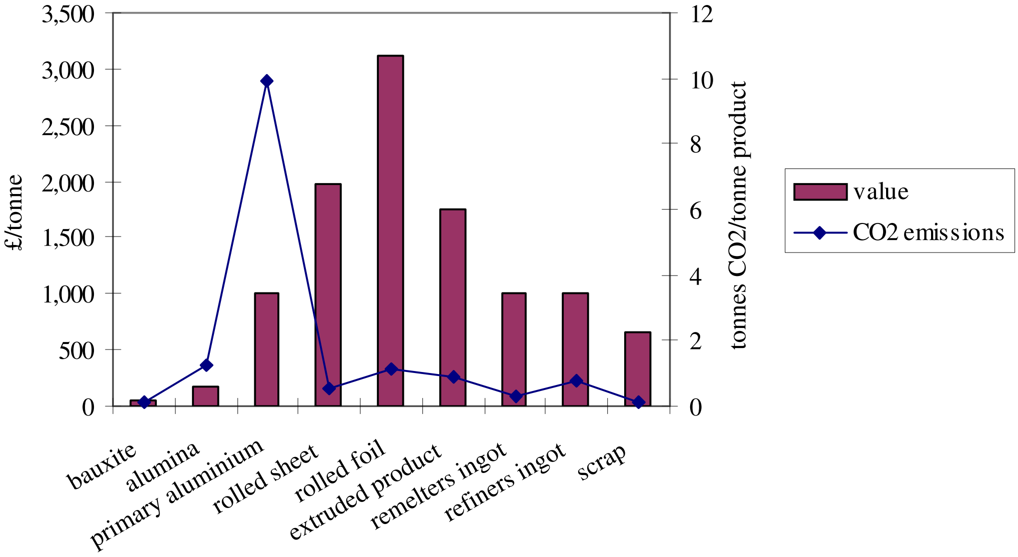

Figure 7.14 Value and CO_2 emissions per tonne of aluminium material categories[30]

As can be seen in Figure 7.14, the materials associated with the early stages of the production chain – bauxite from mining, alumina from the Bayer process, and primary aluminium from electrolysis – have very high emissions of greenhouse gases in relation

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[30] The figures for CO_2 equivalent emissions come from the European Aluminium Association (EAA, 2000) life cycle inventory data, except the figures for bauxite mining which are based on life cycle analysis software, SimaPro, version 5.1, including both foreground and background emissions, and scrap collection, which come from Davis (2004)., and refer to the emissions associated with scrap collection.

to their value (as kg/£). Primary aluminium in particular has very large greenhouse gas emissions[31], some of which come from perfluorocarbons (PFCs) with very high global warming potentials. Semi-fabricated aluminium products, such as rolled sheet and foil and extrusions have higher values and comparatively lower rates of greenhouse gas emissions per tonne of product. Secondary or recycled aluminium, refiners' and remelters' ingot, are comparable to primary aluminium in price and quality while having significantly lower rates of CO_2 generation per tonne of product. The emissions associated with scrap are due to the collection and transport of these materials, which can vary according to the form of the reverse logistics systems.

What these figures point to is the fact that the recycling of materials at the end-of-life product stages reduces not only the amount of waste that otherwise would have gone to landfill, but it also indirectly reduces the environmental impacts associated with the upstream production stages. The consideration of environmental impacts in combination with economic values strengthens the case for materials recovery and reuse; particularly as for aluminium this reduces the emissions of greenhouse gases into the atmosphere.

7.2.4 Value chain findings

The substantive value adding in the UK aluminium production chain comes from the production of aluminium and semi-fabricated products and castings. Variations in the value of unwrought aluminium due to differing production routes are small, but semis and castings can vary substantially in value.

Semis and castings represent the final output of the aluminium industry, and are inputs into various manufacturing sectors. The UK exports a large amount of semis and castings. Imports are increasing, and currently meet 46% of domestic material demand, although only 34% of demand in economic terms. Increasing exports or the share of UK produced output for the domestic market will be important for the industry. While the aluminium industry faces similar issues as the steel industry with regard to heavy international competition and cheap imports, prospects are less bleak as both UK production and demand are growing.

Aluminium scrap is a highly valuable material: the 208 kt of scrap that were exported from the UK in 2001 had a total value of around £146 million, and the 110 kt of imported scrap were worth around £74 million. While the exports of scrap are a source of revenue for scrap collectors, they do represent a significant loss of energy, embedded within the material, to UK aluminium producers.

Despite the high value of aluminium scrap, around 160 kt were disposed of in landfill in 2001. As the cost of disposing the material as well as the value of recovering it would fall on many different and dispersed actors – local authorities, scrap collectors and reprocessors – coordinated efforts to recover more scrap become more complicated. A higher degree of vertical integration, or vertical cooperation, of the aluminium supply

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[31] The figures also include emissions associated with electricity generation for aluminium smelting.

chain would be beneficial from a materials recovery point of view. However, as Aylen (2003) points out, key to recovering scrap is to create a demand for it, as demand finds it own supply.

7.3 Other applications of value chain analysis

In the previous section, the focus was on mapping the value chain associated with the flows of key aluminium materials. The focus could also be placed on costs, of all or particular inputs, or of waste disposal.

The potential applications of the value chain framework are limited more by data availability constraints than by other considerations. For example, the overview methodology could allow an examination of energy costs – Pe1, Pe2, etc, using the associated nomenclature described in Section 5.2.2 – to which could be added the Climate Change Levy, in order to map out the where the costs of this energy tax are the greatest, and to compare impact on primary versus secondary steel producers. However, due to the lack of transparency in the negotiated climate change agreements; the complicated system of exemptions and discounts for this same levy; and the confidentiality with which industry treats its energy costs, such an examination would be very difficult to undertake from outside the industry.

However, to demonstrate the sorts of things the combined MFA-VCA could be used for, publicly available data on main inputs and outputs in key aluminium production process steps have been combined with material and value data collected by the project, for a closer examination of the outputs of residual materials of the UK aluminium industry, and whether these residual materials are sold as valuable by-products and therefore have positive value, whether they are reused or recycled internally, in which case they have positive value but are revenue neutral as no financial transaction takes place, or whether they have negative value because they have to be disposed of as waste.

Waste disposal costs are likely to rise significantly in the UK, with landfill tax rates for active waste, currently at £14/tonne, set to increase at a rate of £3/year from 2005/6 until the long-term of £35/tonne is reached. Therefore, the fate of residual materials is a very policy-relevant matter. Another policy-relevant matter is the emission of greenhouse gases, particularly as the EU emissions trading directive is due to come into force in 2005. The outputs of these gases will therefore be considered as well.

7.3.1 Combining life cycle inventory data with data on material flows and values

The European Aluminium Association (EAA, 2000) has published life-cycle inventory data for major aluminium production processes, based on average European input and output values. The processes are alumina production in the Bayer process; primary aluminium smelting through electrolysis; production of rolled sheet, rolled foil and extruded profiles (semi-finishing); refining old scrap into aluminium; and remelting new scraps into aluminium. There was no information related to casting. Outputs of gaseous emissions are given in the life-cycle inventory, relating directly to the process; to direct and indirect combustion, that is, the fuel used to supply the necessary fuel has been taken into account; and to electricity production.

The output data also indicates whether an output is reused, sold, or disposed of as waste. This information can therefore be combined with material flow and value data collected by the project to estimate the cost or value to the industry of waste disposal and sales of residual materials respectively. The information on the destinations of residual materials has been supplemented by information specific to the UK aluminium industry, provided by the industry.

7.3.2 Outputs from aluminium production processes

The tables below show the key material outputs, their destination, and the associated value, for the UK aluminium industry in 2001. Note that the tables are not a mass balance, but show key solid outputs, their fate as indicated by the EAA survey data, and emissions of greenhouse gases only.

As no smelter-grade alumina was produced in the UK in 2001, this process step has been left out of consideration. For semi-finished products, the division between extruded and rolled products is available in the Alfed annual report (Alfed, 2002), which also contains the amounts produced by refining and remelting. The split of rolled products into 60% rolled sheet and 40% rolled foil was also provided by Alfed.

Table 7.5 Key outputs from electrolysis

Electrolysis: key output 340,778 tonnes of aluminium ingot				
Sold residuals:	Quantity (t)	Value (£)	Value per tonne	Source / comment
skimmings/dross	6,338	£1,901,541	£300	Industry estimate
swarf/turnings	286	£128,814	£450	Industry estimate
Reused residuals:				
carbon	9,581			
steel scrap	2,385			
crushed bath sold	1,397			
refractory materials	570			
Landfilled residuals:				
carbon	3,914	-£109,580	-£28	
refractory materials	7,575	-£212,085	-£28	
soot	409	-£11,450	-£28	Gate fee of £16/tonne (Hummel and Hogg, 2001:38) plus 2001 active waste tax rate of £12/tonne
dross fines	37	-£1,050	-£28	
dust	682	-£19,084	-£28	
hazardous waste	109	-£3,053	-£28	
tar waste	139	-£3,912	-£28	
other solid waste	1,738	-£48,663	-£28	
Greenhouse gases as CO_2 equivalents:				
CO_2	2,619,220			
CH_4	120,078			GWPs from www.defra.gov.uk
PFC (90% CF_4, 10% C_2F_6)	645,979			

Table 7.6 Key outputs from semi-finishing: rolled aluminium sheet

Semi-finishing (1): key output 230,880 tonnes of rolled sheet				
Reused residuals:	Quantity (t)	Value (£)	Value per tonne	Source / comment
skimmings	3,694			
oil	531			
Landfilled residuals:				Gate fee of £16/tonne (Hummel and Hogg, 2001:38) plus 2001 active waste tax rate of £12/tonne
hazardous waste	1,108	-£31,030	-£28	
Greenhouse gases as CO_2 equivalents:				
CO_2	115,209			GWPs from www.defra.gov.uk
CH_4	6,303			

Table 7.7 Key outputs from semi-finishing: rolled aluminium foil

Semi-finishing (2): key output 153,920 tonnes of rolled foil				
Reused residuals:	Quantity (t)	Value (£)	Value per tonne	Source / comment
skimmings	3,694			
oil	531			
Landfilled residuals:				Gate fee of £16/tonne (Hummel and Hogg, 2001:38) plus 2001 active waste tax rate of £12/tonne
hazardous waste	1,108	-£68,956	-£28	
other solid waste	1,639	-£47,407	-£28	
Greenhouse gases as CO_2 equivalents:				
CO_2	167,773			GWPs from www.defra.gov.uk
CH_4	8,727			

Table 7.8 Key outputs from semi-finishing: extruded aluminium profile

Semi-finishing (3): key output 177,100 tonnes of extruded profile				
Reused residuals:	Quantity (t)	Value (£)	Value per tonne	Source / comment
skimmings	3,259			
oil	301			
Landfilled residuals:				
spent bath/sludges	5,136	-£143,805	-£28	Gate fee of £16/tonne (Hummel and Hogg, 2001:38) plus 2001 active waste tax rate of £12/tonne
hazardous waste	283	-£7,934	-£28	
other solid waste	4,073	-£114,052	-£28	
Greenhouse gases as CO_2 equivalents:				
CO_2	152,306			GWPs from www.defra.gov.uk
CH_4	8,182			

Table 7.9 Key outputs from remelting

Remelting: key output 585,300 tonnes of aluminium ingot				
Sold residuals:	Quantity (t)	Value (£)	Value per tonne	Source / comment
skimmings	19,139	£5,741,793	£300	Industry estimate
Landfilled residuals:				
other solid waste	878	-£24,583	-£28	Gate fee of £16/tonne (Hummel and Hogg, 2001:38) plus 2001 active waste tax rate of £12/tonne
Greenhouse gases as CO_2 equivalents:				
CO_2	184,955			

Table 7.10 Key outputs from refining

Refining: key output 248,600 tonnes of aluminium ingot				
Sold residuals:	Quantity (t)	Value (£)	Value per tonne	Source / comment
alumina	29,583	£5,325,012	£180	HMCE average 2001 import value
Al-Mg	214	£299,314	£1,400	Industry estimate
iron scrap	2,983	£59,664	£20	Metalbulletin 2001 iron scrap price
non-ferrous metals (copper)	10,441	£11,589,732	£1,110	LME average 2001 3-month copper price
Reused residuals:				
oil	671			
Landfilled residuals:				
dust	19,217	-£538,070	-£28	
dirt	472	-£13,226	-£28	Gate fee of £16/tonne (Hummel and Hogg, 2001:38) plus 2001 active waste tax rate of £12/tonne
refractory waste	522	-£14,618	-£28	
rubber	6,041	-£169,147	-£28	
other solid waste	845	-£23,667	-£28	
Greenhouse gases as CO_2 equivalents:				
CO_2	199,128			GWPs from www.defra.gov.uk
N_2O	108			

The data on waste generation in these tables are used to construct Figure 7.15, which contrasts the value per tonne of material for key aluminium categories with the waste generated and landfilled[32] in their production. As can be seen in the diagram, relative to their values, waste generation is disproportionately high for alumina production and refining. The high waste generation by refiners points to the presence of environmental trade-offs – while refiners use less energy and save raw materials compared to primary aluminium smelting, a lot of waste is also generated in this process, per unit of output.

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[32] Using EAA (2000) life cycle inventory data on the outputs of waste, supplemented by industry information.

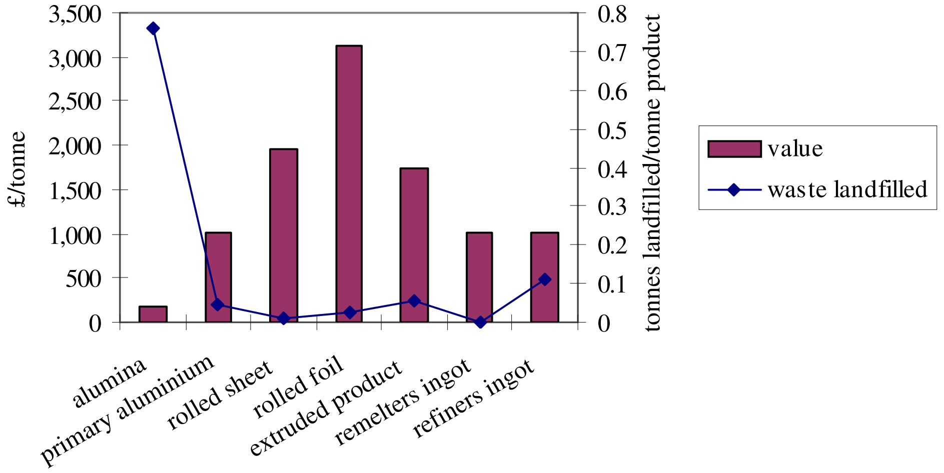

Figure 7.15 Value and waste generation per tonne of aluminium material categories

7.3.3 Findings

Table 7.12 summarises the estimated values and costs of sold and landfilled residual materials respectively for the different stages in the aluminium production chain. The table also displays the estimated CO_2 emissions for the different stages.

While the figures are based on crude calculations, the resulting values can be used as ballpark estimates. Using this framework, the calculations indicate that the value to the UK aluminium industry of selling residual materials is over £25 million. Most of this value comes from the refining sector, which generates a lot of valuable by-products such as alumina, iron, copper and aluminium-magnesium alloys in its production. Remelting produces substantial amounts of home scrap, aluminium skimmings, which can be sold at around £300/tonne. Valuable by-products from the primary smelters are different forms of aluminium home scrap, which have a high value.

Table 7.12: Aluminium: Summary of residual material values

Process	Principal output (t)	Sold residuals	Landfilled residuals	CO2 (t)	CO2 / Principal output (t)
Electrolysis (aluminium)	340,778	£2,030,355	-£408,875	3,385,282	9.93
Semi-finishing (rolled sheet)	230,880		-£76,929	121,512	0.53
Semi-finishing (rolled foil)	153,990		-£116,364	176,500	1.15
Semi-finishing (extruded product)	177,100		-£265,792	160,488	0.91
Remelting (remelters ingot)	585,300	£5,741,793	-£24,583	184,955	0.32
Refining (refiners ingot)	248,600	£17,273,722	-£758,727	199,236	0.8
Total		£25,045,871	-£1,651,269	4,227,973	

Landfilling costs for the industry are £1.6 million, but these costs would rise to around £3 million with a landfill tax rate for active waste of £35/tonne. The refiners are responsible for the highest share of landfilling costs, followed by the primary smelters.

The industry also generates a significant amount of greenhouse gases, according to these calculations around 4.3 Mt of CO_2 equivalents. For electrolysis, refining and remelting, these calculations include emissions directly attributable to the production process as well as the emissions associated with the required electricity generation and transmission. For the semi-finishing, the figures includes only the emissions directly attributable to the process, as no indirect figures were available among the EAA (2000) life cycle data.

The overwhelming majority of the greenhouse gas emissions are associated with primary smelting, which is a very energy-intensive process. However, substantial greenhouse gas emissions also come from the secondary sector, although the output from refining and remelting is much larger than that of primary aluminium. Rolling also has rather high greenhouse gas emissions associated with it, as rolling aluminium, particularly into thin foil, requires a lot of energy.

While this combined material and value framework is very much a work under development, which uses average European data on outputs and their destinations, it demonstrates the potential for an analysis of this kind to pinpoint where there are particular gains to be made from waste disposal reductions and greenhouse gas emissions.

This analysis would be much further enhanced if using actual UK industry input-output data and their actual disposal costs and gains from sales of valuable by-products, rather than the average data and generic values used here. In terms of policy-relevant action, the framework also facilitates a consideration of key actors in an industry and the ownership structures – for example, the number of processing plants, and the level of vertical integration at various stages. This sort of information could be mapped onto the overview diagram of the industry.

7.4 Aluminium value chain analysis: Summary table

Table 7.13 summarises the value chain findings described in Sections 7.2 and 7.3.

Table 7.13 Aluminium summary table

Material category		Domestic production			Imports			Exports			Net Imports = Imports - Exports		
		Weight (kt)	Value (million)	CO_2 (kt)	Weight (kt)	Value (million)	CO_2 (kt)	Weight (kt)	Value (million)	CO_2 (kt)	Weight (kt)	Value (million)	CO_2 (kt)
Bauxite*					163	£8.2							
Alumina					704	£126.7	943				704	£127	943
Aluminium	primary	341	£344.2	3,385	347	£381.6	1,113	263	£292.3	845	84	£89	268
	refiners' ingot	249	£251.6	199									
	remelters' ingot	585	£591.2	185									
Semi-fabricated products	rolled products	385	£935.0	298	405	£777.2	308	219	£385.3	167	186	£392	142
	extruded products	177	£309.9	160									
	castings	129	£621.8	68									
Scrap	new	81	£74.3	83	110	£73.8	12	208	£145.8	23	-98	-£72	-11
	old	672	£436.7										
Scrap to landfill		160	-£4.5	na									

Note: Data on CO_2 equivalent emissions for alumina from SimaPro, for scrap (referring to the transport emissions generated in their collection) from Davis (2004), all other EAA (2000). For imports of aluminium and semifabricated products, the same proportions that exist in the UK in terms of production of sub-categories have been assumed.

*Bauxite imports are not for aluminium production, displayed only for illustration purposes.

The major value adding activities are aluminium production and the production of semifabricated aluminium products and castings. However, aluminium scrap is also a highly valuable material, and the total value of old and new scrap is estimated at over £500 million. In spite of this, substantial quantities of aluminium are disposed of as waste, at an estimated cost of £4.5 million.

The table includes, in addition to weight and value data, estimates of CO_2 emissions associated with the various material categories. These estimates should be treated with caution, but can nonetheless give an idea of the order of magnitude of greenhouse gas emissions associated with the different stages in the aluminium production and use chain.

The final column displays net imports (imports – exports) for the different aluminium material categories. In terms of weight, value and greenhouse gas emissions, exports exceed imports only for aluminium scrap. Greenhouse gas emissions associated with UK aluminium production and use are largely associated with domestic production, with net imports contributing to around one third (1,342 kt) of the CO_2 emissions from domestic manufacture (4,378 kt).

8 PACKAGING WASTE: STEEL AND ALUMINIUM[33]

Paul Ekins

8.1 The EC Packaging Directive

The EC Directive on Packaging and Packaging Waste 94/62/EC came into force in 1994. It is implemented in England and Wales by (i) the Producer Responsibility Obligations (Packaging Waste) Regulations 1997 (as amended) ("the Packaging Regulations", see below) and the parallel instruments in the devolved administrations; and (ii) the Packaging (Essential Requirements) Regulations 1998. The Directive is now being revised and new targets adopted.

8.2 The Producer Responsibility (Packaging Waste) Regulations

Under the EC Packaging Directive, there are effectively three kinds of targets: a material specific recycling target, one for each packaging material; an overall packaging recycling target; and an overall materials recovery target.

The Producer Responsibility (Packaging Waste) Regulations (the 'Packaging Regulations'), which implement this legislation, place three main obligations on businesses (i.e. the 'producers') each year:

1. to register with the Environment Agency, pay a fee and provide data on the packaging handled by the business in the previous year ('the registration obligation');
2. to recover and recycle specified tonnages of packaging waste ('the recovery and recycling obligations'); and
3. to certify whether the recovery and recycling obligations have been complied with ('the certifying obligation').

The second of these obligations is based upon calculations outlined in Box 8.1.

In the UK the Packaging Regulations are implemented through a tradable mechanism called Packaging Recycling Notes (PRNs). These are bought by the companies that have recycling and recovery obligations (or by the compliance schemes set up for the purpose) from accredited reprocessors or accredited incinerators of packaging waste, and used as evidence that the companies have complied with their recycling/recovery obligations. The revenues from the PRNs are supposed to be used by reprocessors to expand both collection efforts and their reprocessing capacity. This system is described in more detail in the next section.

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[33] This chapter has benefited greatly from discussions with Joan Chesney, Pauline Dowling and Rick Hindley from Alcan; Cherry Hamson from Alupro; and John May from Corus Steel Packaging Recycling, whose ideas and other inputs are gratefully acknowledged. Responsibility for any errors and opinions in the chapter remains, however, with the author.

Box 8.1 Obligations under the Packaging Regulations

The characteristics of obligated companies and the nature of their obligations are laid out in Schedule 1 and Schedule 2 of the Regulations. Obligations to recover and recycle waste packaging materials are incurred by all businesses with an annual turnover greater than £2 million (the threshold figure before 2000 was £5 million) which handle more than 50 tonnes of packaging material in one year. Obligated companies are engaged in one of the following activities, and have the following percentage obligations (A%):

manufacturing packaging raw materials - obliged to recover 6%
converting material into packaging - obliged to recover 11% (later revised to 9%)
using packaging to pack products - obliged to recover 36% (later revised to 37%)
selling packaging to the final consumer - obliged to recover 47% (later revised to 48%)
providers of secondary packaging materials - obliged to recover 83% (later revised to 85%)
(the sum of the packer and wholesaler/retailer obligations)

These percentages were worked out only after lengthy negotiations between government and industry. Importers of packaging waste have an obligation which is rolled-up depending on the stage of the packaging chain at which their product is imported (e.g. if packaging is imported to fill for sale to final retailers, the obligation is 6+11+36 = 53%.

The materials for which the obligations apply are waste paper, glass, metals and plastic packaging materials. Wood was included from 2000. The total obligation for the company is calculated using the above figures in combination with the recovery target figures (B%), which are:

for 1998 and 1999	38% (1999 figure revised to 43%, SI 1999 No 1361)
for 2000	43% (revised to 45%, SI 1999 No 1361)
for any subsequent year	52% (revised to 56%, SI 2000 No 3375)

2002 figure 59%

Obligated companies must recover A x B x Q tonnes of packaging waste, where Q is the total amount of packaging and packaging materials handled by a producer in the preceding year. The recycling target figures (C%) are

for 1998 and 1999	7% (1999 figure revised to 10%, SI 1999 No 1361)
for 2000	11% (revised to 13%, SI 1999 No 1361)
for any subsequent year	16% (revised to 18%, SI 2000 No 3375)

2002 figure 19%

Recycling figures are significant since this is the percentage which determines the materials specific proportion of a company's obligation. The material specific obligation is given by the formula A x C x P tonnes where P is the tonnage of that packaging material handled by the producer in the preceding year.

Table 8.1 shows the Directive targets for 2001 and UK performance against those targets (as measured by PRNs), from which it can be seen that the minimum overall recovery target of 50% was narrowly missed (due to non-compliance by one particular compliance scheme). Table 8.1 also shows the Commission Proposal for new targets for 2006, and the Common Position adopted by the Council and Parliament. The latter are likely to become the new targets, with an achievement date of 2008.

It can be seen that the new targets are for 'metals' rather than steel and aluminium separately. The UK Government had to decide what proportion of the target to allocate to each sector. Given that the volume of steel packaging is higher in absolute terms, that a higher proportion of it is the more easily collected commercial and industrial packaging, and that its recycling rate is already higher than that for aluminium, it is likely that the recycling target for steel will be set higher than 50%, and that for aluminium lower.

Table 8.1 Packaging recycling and recovery targets for 2001 and proposed for 2006/8, plus achievements in 2001 (all %)

	Recycling (bottom row Recovery) by Material:					
	Paper	**Glass**	**Steel /Alu.**	**Plastic**	**Overall Recycling**	**Overall Recovery**
Directive Targets for 2001	15	15	15 (each)	15	25-45	50-65
Achieved by the UK in 2001	52	33	37/24	16	42	48
Commission Proposal for 2006	55	60	50 (overall)	20	55-70	60-75
Environment Council Common Position October 2002	60	60	50 (overall)	22.5	55 minimum, 80 maximum	60 minimum, no maximum
Government Targets for Recovery 2008[1]*	70/ 60.5	71/ 60.3	61.5/35.5 50 (overall)	23.5/ 22.9	Min. 95% of recovery	70/ 60.7

[1] First figure is target % of obligated packaging to be recovered; second figure is derived overall level of recovery (i.e. including non-obligated packaging)

Source: Defra website, http://www.defra.gov.uk/environment/waste/topics/packaging/faq.htm consulted 21.8.03, except * press announcement 20 November 2003, http://www.defra.gov.uk/news/2003/031120a.htm, consulted 25.11.03

Table 8.2 Estimated total tonnage of packaging flowing into UK waste stream, plus target fraction to be recycled/recovered, 2003-2008

	2003*	**2004**	**2005**	**2006**	**2007**	**2008**
Aluminium						
Est. total	128,000	141,500	141,500	141,500	141,500	141,500
Target, %	25.25	26.59	28.42	31.17	34.84	37.69
Recyc. material, t	32,320	37,625	40,214	44,106	49,299	53,191
Extra over 2003		5,305	7,894	11,786	16,979	20,871
Steel						
Est. total	684,825	691,189	686,005	680,860	675,754	670,685
Target, %	43	43.16	45.81	48.45	51.09	53.73
Recyc. material, t	294,475	298,317	314,259	329,877	345,243	360,359
Extra over 2003		3,842	19,784	35,402	50,768	65,884
Total pack. waste	**9,950,036**	**10,007,607**	**10,045,358**	**10,084,849**	**10,126,203**	**10,169,467**
Recycling %						**56.02 (55)**
Recovery %	**50.8**	**54.61**	**56.41**	**58.22**	**60.03**	**60.94 (60)**

* anticipated. The Defra press release of 20.11.03 (Defra 2003b, http://www.defra.gov.uk/news/2003/031120a.htm) revised these recycling projections for 2003 to 22.9% for aluminium and 43.8% for steel.
Source: Defra 2003a, Tables 2 [p.18], 4 [p.20], E1 [p.28]

Table 8.2 shows the Government's estimated flows into the UK waste stream of aluminium, steel and total packaging, as well as the UK Government's consultation-paper estimate of the increased recycling of these materials that will be necessary if the combined metals target of 50% recycling by 2008 is to be met. It will be seen that this implies that in 2008 an extra 21,000 t aluminium, and 66,000 t steel, over 2003's expected totals, will need to be recycled. For aluminium this is a 65% increase over 2003's tonnage of recycled material, and for steel a 22% increase. Such an increase represents a substantial challenge. Table 8.2 also shows that, as expected, the Government was proposing a lower recycling rate for aluminium (37.7%) than for steel (53.7%) packaging.

As this report was being finalised the Government announced its recycling and recovery targets for packaging waste for 2008 and intervening years (Defra, 2003b). The targets for 2008 are shown in the bottom row of Table 8.1. Table 8.3 also shows the targets for the intervening years and the extra tonnages of aluminium and steel packaging that will need to be recycled if the targets are to be met. Comparison with Table 8.2 shows that aluminium recovery will now need to be 7,723 t less than was envisaged in the Consultation Paper, and steel recovery 1,251 t more. The combined target of 50% of the tonnage in the waste stream for both metals likely to be a European requirement is still just met, but at 50.12% the targets and projections leave little room for miscalculation.

Table 8.3 Estimated aluminium and steel packaging waste and the obligated tonnage and recovery targets

	Tonnage in waste stream **2004**	**Obligated tonnage 2004**	Tonnage in waste stream **2005**	**Obligated tonnage 2005**	Tonnage in waste stream **2006**	**Obligated tonnage 2006**	Tonnage in waste stream **2007**	**Obligated tonnage 2007**	Tonnage in waste stream **2008**	**Obligated tonnage 2008**
Aluminium	141,500	128,080	141,500	128,080	141,500	128,080	141,500	128,080	141,500	128,080
Recovery (%)	23.5	26	25.3	28	27.6	30.5	29.8	33	32.1	35.5
Tonnes		33,301		35,862		39,064		42,266		45,468
Increase over 2003		1,704		4,265		7,467		10,669		13,871
Steel	691,189	601,035	686,005	601,415	680,860	596,904	675,754	592,428	670,685	587,984
Recovery (%)	46	52.5	48	55	50	58	52	60	54	61.5
Tonnes		315,543		330,778		346,205		355,457		361,610
Increase over 2003		15,025		30,260		45,687		54,939		61,092

Source: Defra press announcement 20 November 2003, Defra 2003b, http://www.defra.gov.uk/news/2003/031120a.htm, consulted 25.11.03

8.3 Packaging Recycling Notes (PRNs)

A company's obligation can be discharged either by the company itself or through joining a compliance scheme, several of which have been established following scrutiny by the Office of Fair Trading.

The nature of the evidence which the company or the compliance scheme is required to provide is particularly important in the context of the Regulations. Until quite late on in the negotiations concerning implementation it had been implicitly assumed that compliance schemes would be responsible both for the financing of waste collection activities, and for arranging for those activities to be undertaken. Because compliance schemes would not necessarily have any direct access to packaging materials (either through collection or reprocessing), it was likely that they would have to discharge their members' obligation through contracting out the necessary activities. This in turn would require some proof that the activity had indeed been carried out. Effectively, it was this situation – the desire for a market-led approach to packaging recycling, and the need for evidence that recycling had in fact taken place – which led to the birth of the Packaging Recovery Note, or PRN. Guidance from the Environment Agency made it clear that PRNs would be issued by accredited reprocessors (and accredited incinerators) and accepted as proof that material had been recycled (or recovered for incineration). This also made it necessary to establish a system for accrediting reprocessors (and incinerators). Thus PRNs were established as tradable compliance certificates.

The system gave rise to all sorts of questions, not least relating to the legal status of the PRN. In response to this and other concerns, amendments were made to the PRN system in 1999 and more were also announced in 2003 (Defra, 2003b), which are discussed further below. Accredited reprocessors are now only allowed to issue PRNs to obligated producers and compliance schemes (or their agents), and they must give obligated producers that deliver waste packaging first refusal on the resultant PRN. This was intended to prevent speculation by non-obligated parties, and to clarify the initial property rights. Reprocessors must also provide an annual return to the Environment Agency showing the total revenue generated from sales of PRNs in the previous calendar year, and the proportions of this revenue used to fund the expansion of the collection infrastructure, additional investment in reprocessing capacity, price support of recyclables, the provision of information and awareness raising, and the development of end-use markets. This reporting requirement was intended to ensure that revenue from PRN sales was put to the use for which it was intended, i.e. to expand the collection and reprocessing infrastructure so as to enable future targets to be met.

The Environment Agency Guidance also made provision for PRNs to be issued by overseas reprocessors that were covered by recognised accreditation schemes operated by local or national governments. However, this was replaced in 1999 by a separate accreditation scheme for exporters of waste packaging materials for reprocessing. Companies satisfying certain requirements are given Agency

Accredited Exporter Status (AAES) and are allowed to issue Packaging Waste Export Recovery Notes (PERNs).[34]

Figure 8.1 gives a diagrammatic illustration of the system.

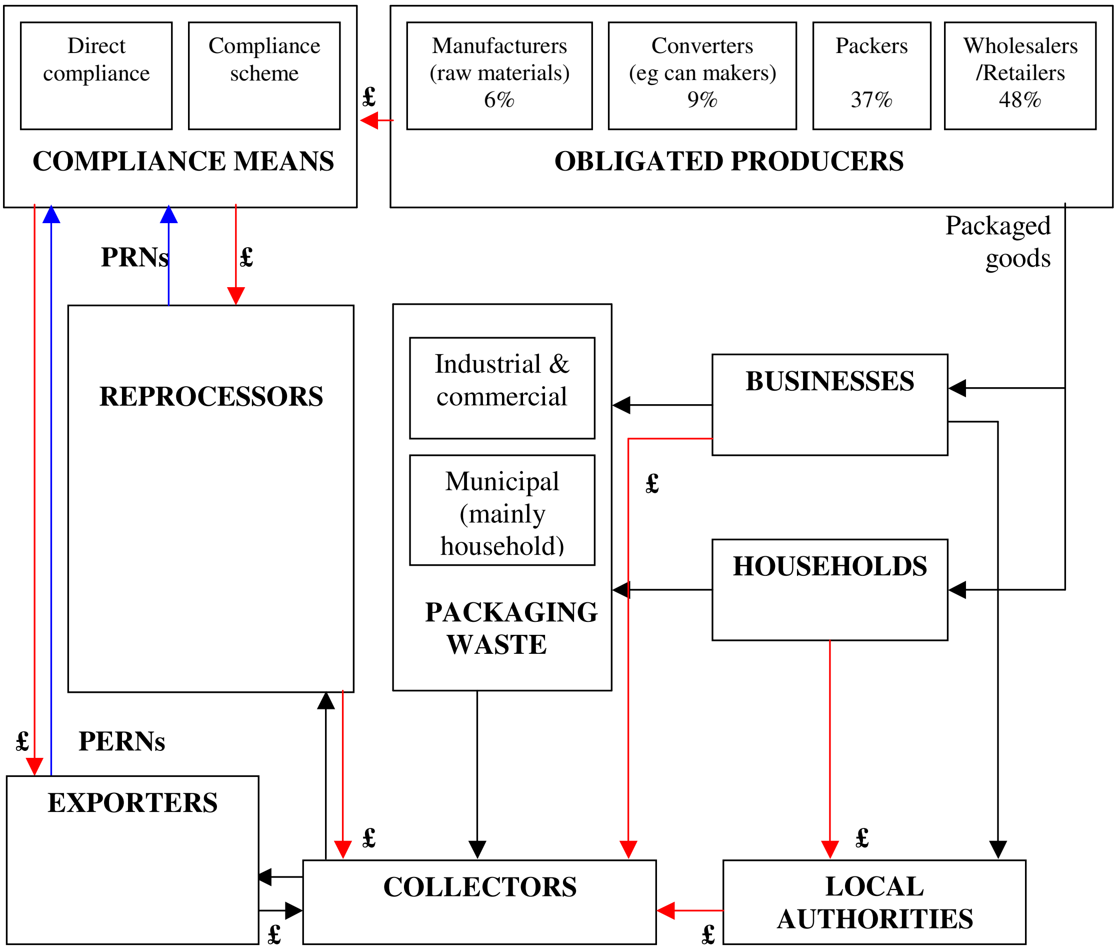

Figure 8.1 Illustration of UK Packaging Waste Regulations Scheme

The diagram may be interpreted as follows. The flows of packaging materials are indicated by the unlabelled (black) arrows. These flows originate with the Obligated Producers and flow with the flow of goods to businesses and households, whence they emerge as packaging waste. This is collected by Collectors. The fraction of materials that is recovered then flows to Reprocessors or Exporters. The former reprocess this into secondary packaging or other recyclate materials, while the latter export it for recycling. The fraction of materials that is incinerated, with or without energy recovery, or otherwise disposed of, is not shown in the diagram. The percentages shown for the Obligated Producers is the relevant percentage obligation for materials or energy recovery, taken from Box 8.1 (the obligation for providers of secondary packaging materials is omitted for simplicity).

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[34] For simplicity the acronym PRN is used for both packaging waste recovery notes and packaging waste export recovery notes.

The recovery is funded by the system of PRNs. These (PERNS from Exporters) are bought by the Obligated Producers from the Reprocessors or Incinerators (not shown here for simplicity), who are the only bodies allowed to issue PRNs. The flow of money (red arrows) and PRN (PERN)s (blue arrows) is shown in reverse directions. The Reprocessors use this money both to invest in more reprocessing capacity and (with Exporters) to pay Collectors to collect more packaging waste. Local Authorities (LAs) also pay Collectors to collect waste, including Packaging Waste, and may in turn be paid for any scrap metal collected. The money flows in Figure 8.1 are shown net of any such payments, and, as noted below, LAs are not allowed to issue PRNs. To the extent that PRNs increase the value of packaging waste, this will benefit LAs because, assuming the market is working efficiently, the revenue generated from the sale of collected materials will to some extent offset what LAs will need to pay Collectors to carry out their municipal waste collection.

Some PRN revenue is certainly invested by reprocessors in ways which directly assist LA recycling and recovery efforts. For example, CSPR (2003) gives examples of investment in community recycling initiatives, equipment, technical support and other means of increasing steel recycling from the household waste stream. However, the extent to which PRN revenues actually support the prices paid for recyclable packaging collected from the household waste stream, or reduce the net cost of waste collection because of such price support, is unclear. In any case PRN revenues in themselves are insufficient to achieve significant increases in the recycling rate for packaging waste in the domestic waste stream. Rather LA recycling schemes continue to rely predominantly for finance on central or local tax revenues, perennial pressures on which have ensured that these schemes continue to expand slowly, and too slowly for the higher rates of collection for recycling required by the above targets to be achieved. The absence of any obligation on LAs to collect or recycle packaging waste means that currently, for example, only about 50 LAs collect glass packaging from doorsteps. The most recent report from the Advisory Committee on Packaging (ACP 2003, pp.6-7) states that this number needs to increase by 80 LAs per year to achieve the 2008 targets. It would seem, therefore, that some mechanism must also be found to interest LAs in collecting and separating packaging from the municipal waste stream. With their own targets denominated by weight and driven by the need to take biodegradables from their waste stream (in line with Landfill Directive targets), with no differentiation by material, LAs are likely to concentrate on heavier and biodegradable materials (such as green waste and newspapers). This issue is returned to below.

The PRN system is widely credited with having enabled the UK to achieve a significant increase in recycling (from 27% in 1997 to 42% in 2001) and recovery (from 30% in 1997 to 48% in 2001) at reasonable cost, estimated at £73 per tonne (Defra website 2003, although see the alternative non-wood cost calculations below). However, as the 2001 Report of the ACP Taskforce (Defra, 2001) noted, one reason for this low cost was because most of the extra material collected was from commerce and industry. It is likely that collecting packaging materials from households will be substantially more expensive (and see the comparison below with the German DSD system).

The PRN (and parallel PERN for exports of waste to be recycled) system generated £280 million between 1998 and 2002. The ACP Report states: "A tougher scrutiny regime should be developed, whereby the Agencies audit how each accredited reprocessor and exporter has spent the money raised through the sale of PRNs and PERNs throughout the previous year" (ACP 2003, p.13).

PRN prices have varied substantially over the past three years. Table 8.4 shows that they rose through the latter part of 2000 and 2001 into 2002, and then declined markedly in 2003. This is likely to have been due to the fact that the Government did not increase recycling targets from 2002 to 2003. In fact, the fall in PRN prices seems to have been foreseen, because in reply to one Frequently Asked Question, the Government replied:

"Some concerns have been expressed to Government that by not setting higher targets there could possibly be an over-supply of PRNs, and a collapse in PRN prices. However it should be noted that the 'no change' policy for 2003 targets does not mean nothing need be done. Indeed, the total of packaging waste in the waste stream rises in 2003 and there will therefore be a higher recovery requirement in any case. In addition, as industry is now aware that a significant uplift in the Directive targets is **certain** we think it would be unwise for industry to put off taking steps to set in hand the development of the recovery and, particularly, collection infrastructure.

"The UK now needs to extract more packaging waste from the household stream but getting new collection systems up and running can take 18 months to two years. We would expect the focus in 2003 to be on taking steps to ensure that the necessary collection systems will be in place to deliver the next Directive targets. Industry must start now to plan where to inject resources into the UK system to develop the infrastructure. At this stage on packaging, this means in particular starting to discuss with local authorities the setting in place of additional collection capacity for household packaging waste." (Defra website, 2003)

However, the collapse of the PRN price that occurred in 2003 suggests that the new collection systems were not put in place to the extent that the Government had hoped. However, it also suggests that, once systems and new reprocessing capacity have been put in place, they can be operated and maintained with relatively low levels of external financial inputs (after all, Tables 8.2 and 8.7 show that recycling tonnages for aluminium and steel in 2003 are expected to increase slightly over 2002's levels despite the low PRN price). If this pattern from the C&I sector can be maintained with collections from the household sector, then it augurs well for the financial sustainability of high levels of recycling once the necessary infrastructure and systems to attain them have been put in place.

Table 8.4 PRN Prices (£/t) for Aluminium and Steel, October 2000-June 2003

	Oct-Dec 2000	Jan-June 2001	July-Dec 2001	Jan-June 2002	July-Dec 2002	Jan-June 2003
Aluminium	15-20	18-25	20-40	26-44	22-50	10-22
Steel	6-15	12-22	18-24	20-32	14-33	7-10

Source: PRN Prices Archive, http://www.letsrecycle.com/prices/prnArchive.jsp

8.4 Recycling of aluminium and steel packaging

The climate change benefits of recycling aluminium and steel packaging are well established. AEA Technology (2001) estimated that recycling one tonne of aluminium avoids 9.074 tCO_2, and of Fe metal 1.487 tCO_2, compared to using virgin materials, because of the avoided energy use and therefore carbon dioxide emissions. In addition, Corus estimates that recycling one tonne of steel packaging saves 1.5t of iron ore, 0.5t of coke, and 62% to 74% of energy, and reduces emissions by 86% and solid waste by 1.28t (May 2003).

This project has estimated that the recycling rates of Al and steel as a whole are as in Tables 8.5 and 8.6.

Table 8.5 Estimated scrap arisings and recycling rates for aluminium

[Metric tonnes]	Average life span [years]	End-of-life scrap arisings modelled with Weibull distributions		
		1999	***2000***	***2001***
1 Transport	13	215910	225740	232980
2 Building/Construction*	35	35820	39080	42510
3 Engineering	17	79340	87650	93990
4 Packaging*	1	131080	136440	137010
5 Consumer durables	7	79650	86190	95850
6 Other	10	28070	23540	19580
Total end-of-life scrap arisings		569870	598640	621920
Prompt scrap arisings		77770	82648	80778
Total arisings		647640	681288	702698
Actual UK scrap recovery (UK consumption-imports+exports)**		417573	457564	546198
Inferred recycling rate [%]		64	67	78

*Assuming that input into packaging in 1999, 2000 and 2001 was 188 000 tonnes (http://www.alupro.org.uk/frame9.htm) and that yearly input into construction in 60s and 70s was 100 000 tonnes

**No data for UK consumption in 1999 and 2000, have assumed 2001 figure for both years

Table 8.6 Estimated scrap arisings and recycling rates for iron and steel

[Metric thousand tonnes]	Average life span	End-of-life scrap arisings modelled with Weibull distributions		
	[years]	***1999***	***2000***	***2001***
1 Mechanical engineering	10	1920	1959	2002
2 Electrical engineering	7	598	611	627
3 Ship building	60	3	4	5
4 Vehicles	13	2228	2292	2340
5 Structural steelwork and Building & civil engineering	60	1031	1050	1070
6 Metal goods	15	1210	1224	1234
7 Cans and metal boxes	1	428	424	392
8 Boilers, drums and other vessels	10	613	605	596
9 Other industries	25	1584	1675	1747
Total end-of-life scrap arisings		9615	9844	10013
Prompt scrap arisings		1267	1273	1383
Total arisings		10882	11117	11396
Actual UK scrap recovery (UK consumption-imports+exports)		7722	8439	8064
Inferred recycling rate [%]		**71**	**76**	**71**

The inferred recycling rate for aluminium rose from 62% in 1999 to 73% in 2001. For steel the recycling rate rose from 71% to 76% over 1999-2000, but then seems to have fallen back to 71% in 2001.

Table 8.7 Recycling of aluminium and steel packaging waste for various years

	Aluminium	**Steel**
1999		
Total		
Recycled	15402	225216
% Recycled	(28)	
2000		
Total		
Recycled	16299	238668
% Recycled	(33)	
2001		
Total	120958	751565
Recycled	29030	278079
% Recycled	24 (33)	37
2002		
Total	128193	691576
Recycled	31279	290462
% Recycled	24.4	42

Source: Defra 2003a, Table 1, p.16, except for aluminium figures in ( ), supplied by Alcan

The relevant recycling statistics for aluminium and steel packaging are as in Table 8.7.

8.4.1 Aluminium packaging

The ACP (2003) Report says that ‘further investigation of … aluminium statistics is urgently required’ (p.1) and ‘there is an issue of confidence in the quality of data on aluminium’ (p.6). The issue appears to be that, prior to 2002, the statistics were kept by the aluminium industry, and the figures in ( ) in Table 8.7 indicate that a packaging recycling rate of 33% (2000, 2001) was derived from all recyclers. In 2002, when PRNs were used for the first time to determine the recycling rate, only registered reprocessors were included in the statistics. The drop in the recycling rate to 24% reflects the exclusion of non-registered reprocessors.

Table 8.8 shows the estimates from Alupro of the aluminium packaging arising in the waste stream, and its source. It will be seen that the total of obligated packaging for 2002 differs between Table 8.7 (128,193 t) and Table 8.8 (121,100 t) and is another source of discrepancy in the aluminium statistics. According to the industry (Hamson 2003), the reason this time is due to Defra (unlike other EU Member States) interpreting the obligation as including the metal in composites, laminates and metallised plastic film (e.g. crisp wrappers). The issue is still under discussion, but in its setting of new targets for aluminium packaging under the Packaging Regulations Defra has assumed a flow of aluminium packaging of 141,500 tonnes p.a. over 2004-08 (see Table 8.3).

Table 8.8 also shows that 71% of obligated aluminium packaging, and of unrecycled obligated packaging, comes from households. (It may also be noted that a further 22% of unrecycled obligated packaging is ‘front-door’ C&I packaging, where the challenges of collection and recovery are greater than those of traditional ‘back-door’ C&I waste.) Although the household recycling rate is close to the average for packaging as a whole, the large proportion of household arisings means that, if recycling of aluminium packaging waste is to be increased, the increase will need to include increased recycling of household packaging waste. Certainly the ACP (2003:6) Report came to this conclusion: “Aluminium, glass and steel will have to come largely from domestic sources”.

Table 8.8 Aluminium packaging arising in the waste stream. Analysis of aluminium packaging entering the UK market place and recycling estimates by source of arisings (December 2002)

	Total net tonnes	Obligated packaging tonnes	House-hold tonnes	Front-door C&I tonnes	Back-door C&I tonnes	Notes
	Market		Waste Arising			
Drinks cans	82,100	82,100	54,200	24,900	3,000	(1) Estimated 700 tonnes retailers' spoilage and 2300 tonnes arisings at pubs, clubs etc.
Food cans	1,600	1,600	1,600	0	0	
Foil trays	15,100	15,100	13,100	0	2,000	
Dairy lidding	3,600	3,600	3,600	0	0	
Unbacked foil, e.g. choc.	3,500	3,500	3,500	0	0	
Petfood trays	3,700	3,700	3,700	0	0	
Aerosols	4,500	4,500	3,000	750	750	
Closures	6,000	6,000	3,000	0	3,000	
Beer kegs	1,000	1,000	0	0	1,000	(2) Shown as 1,000 tonnes to maintain consistent totals. In reality, 2,000 tonnes of kegs arise as waste annually, with only 1000 tonnes entering the re-use market
Housefoil	12,800	0	0	0	0	
Foil	12,300	0	0	0	0	
Alu lids on steel drinks cans	8,100	0	0	0	0	
Total	**154,300**	**121,100**	**85,700**	**25,650**	**9,750**	
Recycled		**40,400 (33%)**	**28,300 (33%)**	**7,600 (30%)**	**4,500 (46%)**	(3) The full 2,000 tonnes of kegs recycled annually are included in the 4,500 tonnes shown here
Left in waste stream		**80,700**	**57,400**	**18,050**	**5,250**	

Definitions (amendments from source in *italics*):

Back-door C&I means: Used aluminium packaging discarded by commercial and industrial companies/ organisations as a result of their commercial activities e.g. drinks cans discarded at the back of licensed premises.

Front-door C&I means: Estimate of used aluminium primary packaging discarded by individuals at 'commercial' locations such as the workplace, schools, and sports and leisure facilities. It is suggested that these locations provide opportunities for mixed collections of other valuable recyclables such as laser cartridges, fluorescent tubes and office paper with drinks packaging.

Aluminium C&I packaging is, without exception, primary packaging, whereas most C&I packaging for other materials is secondary and tertiary packaging *(Hamson [2003] says that 93% of Al packaging is primary packaging, i.e. sold to final consumers of the packed product.)*

Defra comment: housefoil should be deducted from the above table because it is not packaging

Source: Defra 2003a, Consultation Paper, Appendix 2, p.113, data from ALUPRO, http://www.defra.gov.uk/corporate/consult/packaging-reg/consultdoc.pdf,

8.4.2 Steel packaging

Table 8.9 shows Corus's estimate of the composition of steel packaging in the waste stream, together with the amount estimated to be recycled in 2003. It can be seen that, with 88% of C&I packaging already being recycled, almost all increases in recycling in order to meet the recycling targets (as set out in Table 8.1) in future years will need to be collected from households.

Table 8.9 Steel packaging in the waste stream, 2002

Type	**Quantity ('000 tonnes)**	**Recycled '000 tonnes (%)**	**Target 2008 %**
Commercial and Industrial (C&I)			
Drums, kegs, steel strapping, baling wire, roll cages	200	175 (88)	
Household			
Food cans	225		
Petfood cans	100		
Drinks cans	65		
Aerosols	30		
Paint cans	20		
Closures	10		
Fancy boxes, tins, giftware	15		
Oblong containers (DIY products, automotive etc.)	10		
Polish containers and other household	10		
Other	5		
Total Household	490	125 (26)	
TOTAL PACKAGING	690	300 (43)	53

Source: May 2003

8.5 Operation of the PRN scheme[35]

The following discussion of the PRN scheme focuses on three issues:

- First, the way in which the costs of compliance are distributed across different actors in the economy;
- Secondly, the scheme's achievements thus far and the related costs; and
- Thirdly, the potential for the scheme to deliver on future targets proposed under a revised Packaging Directive.

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[35] This part of the report draws on work jointly undertaken with Dominic Hogg, Eunomia Consulting, whose input is gratefully acknowledged. Responsibility for the views expressed, however, rests with this report's authors alone.

8.5.1 Who is responsible under Producer Responsibility?

The concept of producer responsibility implies that obligated entities should be responsible for the actions which are sought as outcomes of the measures implemented. In the case of packaging, this ought to imply that obligated entities are responsible, directly or indirectly, for the costs of recycling and recovering packaging to the required levels. This was intended to be the essence of 'extended producer responsibility'.

When examining the UK system, based upon PRNs, it would be tempting to take the cost of acquiring PRNs as the cost of complying with the Directive. Yet this is clearly not the case. The costs of collection of the materials being collected is not always being borne by those responsible, except in the instances where those obligated achieve part of their obligation through their own activities (in which case, they pay for the collection and recycling of these materials).

This is not true of those materials which enter the household waste stream. In these cases, the costs of materials collection and despatch for recycling (net of any revenues received for the recyclables and any support provided by reprocessors in terms of equipment, communications etc.) are being met by local authorities (LAs), and hence, taxpayers in general. It could be argued that some of the value from PRN sales will be passed on to the waste collectors as the balance between supply of materials and demand tightens and the commercial waste stream becomes an increasingly important source of packaging material in order to meet the recycling targets. There are indeed some good examples of PRN revenues being directly applied to the household waste stream, but the degree to which PRN revenues are actually reflected in the prices of packaging materials from household waste is a) difficult to estimate, and b) less than transparent. From the perspective of a LA treasurer, the potential instability of such revenues is unlikely to constitute an argument to implement a collection system for packaging where none currently exists. The arguments are likely to relate to other issues, among them, national targets, EU-related targets, the financial situation (excluding PRN revenue), and broader environmental/political concerns. The unstable nature of the potential revenue related to market-determined revenues from PRN sales is unlikely to persuade a LA to do what it otherwise would not. The fact that LAs have been generally so slow and unwilling to set up packaging collection schemes indicates that they regard them as a net cost.

This may be seen as unproblematic as long as there is material remaining which a) has a relatively low marginal cost of collection, and b) which can be accessed relatively swiftly. But it has been above that, as recycling targets are stepped up, it will become necessary to increase the collection of packaging waste from the municipal waste stream. This material has a higher cost of supply and is not so readily 'mobilised' because of the nature of LA collection contracts.

Yet, there is no stable relationship between obligated companies, compliance schemes, LAs and reprocessors. Indeed, the relationship is unstable at each of these points. Compliance schemes need to compete for customers – the obligated companies – presumably by keeping subscription fees low and acquiring PRNs at a competitive price. This competition makes it unclear, from year to year, how many PRNs a given compliance scheme will need to hold to discharge the obligation of its members. Given that uncertainty, the likelihood of compliance schemes making significant investments themselves might be considered to be reduced. This in turn is likely to make it more risky for such schemes to enter into the longer-term contractual relationships generally required by LAs.

More importantly, the degree to which the costs of compliance with the Directive will be met by those by whom they should be met (the obligated parties) remains in question. To the extent that collecting packaging from households is necessary to meet the Directive targets, those costs should, under extended producer responsibility, be met by the obligated parties themselves. Yet at present, the great majority of packaging collection from households is funded by local authorities, and the revenues from the sale of recyclables, and the direct support from PRN revenues, cover only a small part of the overall collection cost. This implies that instead of the costs of compliance being fully internalised by obligated parties in product prices, the costs of compliance are met, and may be met to an ever increasing extent, through general taxation. This is hardly a way of implementing the polluter (and hence, consumer) pays principle. The potential consequences are:

1. A reduction in the degree to which incentives for changing the nature of packaging impinge upon obligated entities (and hence, a continuation of 'producer irresponsibility', especially where packaging entering the household waste stream is concerned); and
2. A concomitant distribution of compliance costs which is increasingly *insensitive* to the decisions made by producers and consumers (since a growing proportion of the full costs of compliance will be those associated with collection of household packaging, the costs of which will fall on taxpayers in general, not the obligated parties).

This failure to implement the polluter (and hence, consumer) pays principle is a fundamental flaw of the UK system.

8.5.2 Performance of the UK scheme

The performance of the UK scheme is shown in Table 8.10 below: between 1998 and 2001, recycling increased by just over 1 Mt (although, as shown in Table 8.1, the 2001 target of 50% recycling was not met). The system was clearly compromised by the failure of a major compliance scheme, Wastepack, to discharge its obligation. This highlights points made above concerning the competitive nature of the compliance scheme business. Wastepack was not subject to any automatic sanctions even though clearly, in a market oriented scheme, the depressed demand for PRNs reduces their price and reduces the finance available to deliver (future) compliance.

Table 8.10 Recycling of packaging materials, 1998-2001

	Actual ('000 tonnes)			
	1998*	**1999***	**2000**	**2001**
Aluminium	14.5	15.4	16.3	29
Steel	182.4	225.2	239	278.1
Plastic	125.5	198.5	204.4	270
Glass	503.8	582.6	715	735.6
Paper	1894.1	1820.7	1879.7	2030.9
Wood	170	94	296.6	574
Total recycling	2890.4	3010.3	3351.1	3917.6
EfW	448.4	496.3	500.8	500 (e)
Total recovery	3338.7	3506.6	3851.8	4417.6
(increase w.r.t. 1998)		167.9	345.2	1078.9
(increase excl. wood)		243.9	218.6	674.9

Source: Defra

* No data for Northern Ireland in 1998. Estimated data included in total recycling and EfW for 1999, but not in individual material figures.

Tables 8.10 and 8.11 show the significance of wood recycling in the overall increase in recycling over 1998-2001. The increase in recycling of packaging materials can also be illustrated through reference to the split of domestic versus foreign reprocessing (see Table 8.11). Domestic reprocessing of dry recyclables, excluding wood, and paper and board, has increased by 362,000 tonnes. Domestic reprocessing of paper and card has actually fallen and the increase in tonnage collected has led to an increase in exported fibre packaging. At the same time, the principal destination for the funds from the PRN scheme is to domestic reprocessors of paper packaging (see Table 8.12).

Table 8.11 Increase in UK Reprocessing and Export of Packaging Waste, 1998-2001

Increase (1998-2001), '000 tonnes		
	UK	Exp
Paper	-43	179
Glass	261	-30
Plastics	88	56
Steel	1	95
Aluminium	12	3
Wood	443	0
TOTAL	762	303

Tables 8.11 and 8.12 show that, in total over 3 years, through the PRN scheme, £121 million has achieved a net increase in the collection and reprocessing of dry

recyclables (excluding wood) of 319,000 tonnes. The cost per tonne of this incremental increase is therefore around £125 per tonne.

Table 8.12 Recycling revenues, 1999-2001

PRN Revenues 1999-2001 (£ millions)			
	PRN	PERN	Total
Paper	69.4	3.9	73
Glass	16.6	0.7	17
Plastics	15.1	2.7	18
Steel	10.5	4.4	15
Aluminium	0.8	0.1	1
Wood	8.6	0	9
Total	121	12	133

8.5.3 Comparison with the German DSD scheme

One can compare this performance with other schemes. The German DSD scheme is expensive by repute. Between 1992 and 1995, the DSD scheme increased collection of packaging from 920,000 tonnes to 4.92 Mt, an increase of 4 Mt. The current figure is 5.55 Mt. The average cost of this scheme is approximately £228 per tonne. For the 'incremental tonnage' (i.e. the last tonne collected), the scheme costs some £278 per tonne.

On the surface, this seems expensive. Yet under the DSD scheme, local authorities do not pay a penny for the collection of packaging materials. The whole system is financed by payments from packaging producers. The Advisory Committee on Packaging estimates that in 2001, 709,000 tonnes of packaging were collected from households (ACP 2003). The producer responsibility principle suggests that the net costs of this collection ought to be (and in the German system are) born by producers.

However, the DSD and PRN schemes are not strictly comparable. One principal difference in the schemes in respect of costs is that the UK system to date has largely focused on commercial and industrial packaging. The DSD system focuses on household packaging. Another is that the DSD system recovers a far higher proportion of waste, and it is likely that the marginal cost of such recovery increases with the proportion recovered.

One reason for the household focus of the DSD system may have been that the Germans recognised that it was probably in the interests of commercial and industrial entities to recycle anyway (especially at higher German disposal costs). Hence, the concept of extended producer responsibility could most usefully be deployed in focusing on the household waste stream. This would explain why the German scheme has led to far greater changes than the UK system. Compliance with the European Directive is not the prime concern of the German system, which pre-dates the

Directive itself. There, the costs of recycling packaging are met not by municipalities, but by producers (and hence, presumably, consumers). The flip-side of the costs being higher for packaging producers is that the incentive to change materials used in packaging is greater.

All this is not to deny that the German scheme is expensive even judged on its own terms, and this is partly related to the nature of the contracts awarded in the early days of the DSD scheme. These are currently being re-appraised/negotiated. Nor has the system been without other flaws (such as its initial focus on collection rather than reprocessing, which led to the build-up of 'mountains' of unprocessed waste). The intention here, however, has been to show that the cost burden falls very firmly on the producers, and that the contractual nature of the system led to very significant increases in the capture of packaging waste over a short period of time. Since the collection system is 'free' to local authorities and householders, and since the system functions in the context of widespread charging schemes for refuse collection, it is hardly surprising that the capture rates for materials are very high in Germany. If the UK system achieved the sorts of result that the German system does, the costs of such an achievement would, arguably, not be radically different. Furthermore, in the absence of changes in legislation allowing household charging schemes, it seems possible that the UK *could not* achieve what the German system does.

8.5.4 Future prospects

Much interest has been focused, in the EU, on the UK scheme. The market orientation has been the focus of much discussion. Some appear to have pronounced upon the desirability of the scheme even though at its first test (the 50% target in 2001), it failed. One problem here is that the assumptions under which orthodox economists analyse the likely success or failure of market-based schemes tend to relate to more-or-less well functioning markets populated by actors imbued with a high level of rationality. Under these assumptions, the superiority of a market-based scheme essentially follows from the underlying assumptions made.

These assumptions break down where the rigidities of the market lead to significant lags in the response of 'the market' being analysed. Furthermore, when one looks at the issue of household waste collection, then given the current absence in the UK of any possibility of incentivising participation in recycling schemes, any assumptions based around price incentives are likely to miss the point – the householders ultimately being relied upon to deliver materials, which in turn makes compliance possible, are not subject to any price incentives. What, then, is the relevance of a market-based system, a critical component of which must be the collection of material from the household waste stream, when no incentives are permitted at the household level? It is striking that the UK, the only country in the EU where charging systems are prevented by law, is the only Member State that has chosen to implement the Packaging Directive through a market mechanism. This reflects, in part, the lack of consideration about household waste collection in the design of the scheme (in which process local authorities were not represented at all).

In these circumstances, it remains questionable that the UK scheme will attain the targets being envisaged as set out in Table 8.1. A significant degree of coordination is likely to be required from a range of actors, many of whom function under various competitive pressures that make a stable form of coordination unlikely where household packaging waste collection is concerned.

Ironically, to the extent that the system does achieve the required targets, this might be a consequence of the overlapping targets in UK waste management policy. The statutory recycling targets in England will almost certainly draw additional material from the household waste stream, though how much of this will be packaging remains to be seen. To the extent that this material facilitates achievement of the targets, and in the absence of substantially increased financial flows from the packaging sector, it will enable packaging producers to continue to pass on the net burden of compliance to taxpayers in general. The failure to ensure that packaging producers meet the proportion of the household waste collection costs associated with packaging waste collection, and therefore make it more likely that LAs will actually collect packaging waste, must be seen as a failure to act on the producer responsibility principle.

8.6 Conclusions and recommendations

8.6.1 Conclusions

The arguments above lead to the following general conclusions:

C1 It seems likely that the PRN system has generally contributed to a cost effective increase in the recycling of packaging waste in the UK.

C2 However, another reason why UK compliance costs with the Packaging Directive have appeared low is because not much has been achieved (certainly by comparison with other countries) – UK based recycling is up 762,000 tonnes whilst collection has increased by over one Mt. This is an increase in collection of around 11% of all packaging waste, and an increase in UK reprocessing of around 8%;

C3 With respect to packaging in the household waste stream, the recycling system is ‘subsidised’ by tax-based funding of local authority collections (compared with the German system where the DSD funds support all of the costs of collection and recovery, and on present trends this subsidisation looks likely to increase);

C4 The role played by wood waste packaging has been much more significant than was anticipated. Tables 8.11 and 8.12 show that although recovery of wood packaging received among the lowest levels of financial support (in unit terms), it contributed over 40 per cent of the growth in recycling. Had this not occurred, it is doubtful that compliance with the targets in the 1994 Directive would have been possible without a substantial increase in PRN/PERN values for all the other materials, perhaps doubling the compliance costs incurred by obligated businesses. (However, the figures for wood recycling are based on the assumption that no wood packaging was being reprocessed prior to the introduction of the Packaging Regulations, which seems unlikely, so the increase in reprocessing of wood, and therefore the total increase, may be much lower than figures are suggesting). It is notable that in its press announcement of November 2003 (Defra, 2003b) the Government acknowledges that wood recycling data for 2003 is unclear. This is likely also to have been the case in earlier years.

C5 The lack of a viable mechanism for sanctioning failing compliance schemes has led to lower levels of demand for PRNs, reducing the marginal costs of packaging recycling and recovery in the UK, and hence, the prices paid for PRNs.

C6 The fluctuations in the PRN price have not helped planning for the development of either the collection or reprocessing infrastructure. PRN prices seem strongly driven by recycling targets. It seems that unless targets continually increase, PRN prices fall back, which hinders the smooth development of the collection and reprocessing infrastructure.

C7 A positive conclusion from the price sensitivity to PRNs to targets is that, in the industrial and commercial sector at least, it seems that once collection and reprocessing infrastructure is in place, reduced levels of subsidy are required to keep it operational. It is not yet known whether this would also apply to the household sector, but industry sources suggest that it is likely (Chesney 2004)

C8 The volume of steel and aluminium and other packaging in household waste, the increasing targets for recovering packaging waste in the future, and pressures to recover other waste streams from households, make it both desirable and necessary for household waste to play a larger part in meeting the packaging waste recovery targets in the future than it has in the past. This means that local authorities are going to need greater levels of recycling finance. To be consistent with the producer responsibility principle, this finance should be provided by the packaging industry (and therefore the cost passed on in the cost of the packaging) rather than the taxpayer.

8.6.2 Recommendations

These conclusions suggest the following recommendations in respect of steel and aluminium to ensure that the recycling target for 2008 is met:

R1 In order to facilitate the steady and predictable development of recycling infrastructure, recycling targets should be set to increase on an annual basis. It would seem prudent to set the targets slightly higher than the statutory minima. It was seen from Table 8.1 that Defra (2003b) has set targets to increase on an annual basis to 2008, but these targets are still at the minimum level permitted by European level so that there is little room for the kind of miscalculations and data problems that have occurred in the past.

R2 To ensure that PRNs maintain the price necessary to develop new recycling activities, there should be sanctions for compliance schemes (passed on their member obligated producers) that fail to meet their obligation to purchase PRNs. Defra (2003b) did indeed announce that scheme operators would henceforth be legally responsible for discharging their recycling obligations, and would be liable for penalties if they failed to do so.

R3 To apply the concept of producer responsibility to the household waste stream, the packaging industry should provide increased funds to local authorities (LAs). To give an incentive to LAs to collect packaging waste from households (of all kinds, not just steel and aluminium), they could be paid a premium price for such waste by reprocessors, funded out of PRN revenues (this would in turn require a higher PRN price, which would incentivise packaging producers to be more efficient in their use of packaging).

R4 It seems likely that the most efficient resource recovery infrastructure, and the one best suited to give effect to the proximity principle, would be integrated local facilities which handled both commercial and industrial waste along with municipal waste. This would enable economies of scale in waste handling to be achieved from the waste from a relatively small area. The Government should provide incentives, perhaps out of landfill tax revenues, for the creation of these integrated local waste management facilities, from which the recovery of all materials ending up as packaging waste could be maximised irrespective of their source.

9 SUMMARY AND CONCLUSIONS

9.1 General methodological observations

Material Flow Analysis

The time series MFA methodology, outlined in Section 2, was employed in the analysis to track flows and stocks of iron, steel and aluminium in the UK. The study highlighted the importance of modelling iron/steel and aluminium stocks contained in goods in use. Iron/steel and aluminium products from the upstream production processes are either exported or incorporated into new goods in the fabrication and manufacturing processes. New goods entering use are added to the material constituting stock- in- use. These goods then remain in use until, according to their range of service lives, they leave the stock-in-use as end-of-life (EOL) scrap. The flow of new goods into use is accounted on a yearly basis, to give a time series in the form of tonnes per year. However, the rate of EOL scrap flowing out of the stock- in-use is lower than that of new goods going in. This results in an increasing accumulation of stocks of iron/steel and aluminium in the economy. These significant stocks of iron/steel and aluminium in goods in use mean that a simple "current account" approach to mass balancing will be misleading. A time series approach was therefore used to reflect the accumulation of stocks in use and hence to model EOL scrap arisings.

The crucial element in modelling goods in use and EOL arisings lies in the analysis of service lives. The concept of service lives resembles the residence time distribution established in chemical reactor theory (Danckwerts, 1952). By adapting this theory, the service lives of different application categories were modelled using Weibull and log-normal distributions, for comparison with a fixed service life span. This approach in modelling scrap arisings, which has not previously been used on material flow data, was proved to be valid as it enabled the material balance in the materials cycles of both iron/steel and aluminium to be closed: metal emerging from use could be largely balanced with recovered and landfilled metals.

Moreover, incorporating the temporal (time series) dimensions into the MFA enables understanding of not only the current material flows but also the past patterns/trends and, hence, insights on the evolution of these trends. The time series approach demonstrates further strength during the modelling of EOL scrap arising as it sheds light on the effects of human activities over time. It is well recognised that successful application of the methodology depends largely on data availability. For both metals, difficulties in acquiring the necessary data were experienced, but guidance from experts in the industries and their respective trade organisations helped in closing most of the data gaps.

The limitations of the research are associated primarily with the complexity of the supply chains and the poor availability of certain types of data:

1. Data on upstream material flows for both the iron and steel and the aluminium supply chains are relatively readily available, either from industry specific associations or government statistics. Tracking materials further downstream in the chain, when they become embedded in goods, becomes more difficult.

Therefore, the MFA assumed a constant content of these metals in broad categories of goods over the time period studied. In reality, however, metal content will change over time.

2. Classifications systems such as the SIC, SITC and CN, are useful but have not been designed with the aim of tracking specific materials through the economy. The allocation in the project of different metal categories to SIC codes may therefore contain omissions or erroneous inclusions. Moreover, broad categories of goods were assumed to contain uniform fractional metal content and to be associated with constant prompt scrap arising rates. In reality, however, there are variations in these two variables across the goods belonging to any particular category.

3. The approach used in EOL scrap arisings modelling by deploying residence time theory is realistic and theoretically sound as it considers the variation of the time delays between flows into and out of the stocks in use. It smoothes out input flows, i.e. the flows of iron/steel and aluminium contained in goods entering the use phase, as all inflows into use in the same year cannot in practice leave the stock -in-use as EOL scrap simultaneously (i.e. the case of fixed life span). Comparison of the results from the three different distributions of service lives and sensitivity analysis of both iron/steel and aluminium EOL scrap arisings indicates that the approach is most valuable when there is year-on-year change in demand, and it was therefore more useful for the aluminium than the iron/steel MFA. In general, it will be more useful for material flows with significant year-on-year variations.

4. The MFA used a simplified approach to infer the annual tonnage of metals contained in goods going into use. Deliveries to downstream manufacturers, minus the prompt scrap generated by those manufacturers, were assumed to equal the amount going into use in that same year. Long lead times, complex supply chain structures, and multiple distribution channels can all delay this process. This stock issue was addressed by the sensitivity analysis of the scrap arisings model; however, sufficiently accurate data to adequately conduct the analysis were not available.

The time series MFA approach required material flow data over the past 30-40 years. This requires data to be collected and compiled in a consistent way. However, there have been changes (e.g. revisions of SIC and SITC classifications, industrial reporting formats, etc.) for both iron/steel and aluminium data, which led to inconsistent or sometimes distorted data sets. Material-specific measures were taken to attempt to eliminate the misleading effects of these changes on the data series.

Value chain analysis

The concept and methodology of the value chain analysis were explained in Section 5. The value chain analysis, together with the material flow analysis, has generated interesting insights with regard to the resource productivity of the iron and steel and aluminium industries; mapped the value chain of the industries; and analysed iron and steel and aluminium waste flows in the context of the packaging waste regulations.

As for MFA, limitations of the methodology are associated with different types of data availability. However, this problem can be compounded when combining material flow and value chain data. Specific difficulties concern:

1. Resource productivity indicators combining economic and material variables need to have the same boundaries. As material and economic data tend to be collected by different agencies and for different purposes, combining the two can present great obstacles related to definitional uncertainties. Time series analyses of productivity are important to assess long-term trends; however, information on economic variables at the sector or industry level, using SIC codes, are complicated by changes in the economic structure and subsequent revisions in classifications.

2. Mapping the value chains associated with the steel and aluminium industries involves identifying representative values for the broad material categories identified. At this stage, needs and data requirements between the MFA and the VCA tend to diverge. Small additions of foreign materials have a small impact on the mass of a metal, but can have a disproportionate impact on the value of the resulting product. Similarly, changing the shape of a metal does not alter its mass, but the value can increase substantially to reflect the necessary energy and other inputs required to change the shape. Generally speaking, value chain analysis requires a more detailed level of breakdown of material categories than the material flow analysis. Where this is not possible, representative values from a range have to be chosen.

3. Related to point 2 is the fact that while mass is a constant, values, per unit of mass of a material, change for a myriad of reasons: economic cycles, exchange rate fluctuations, competition, supply and demand levels, etc., all influence values. Care has to be taken to use value data from a specific year and be aware of any long-term trends or short-term impacts.

4. A lot of value data is also confidential. Published prices for quantities of materials or energy vary according to the specifics of the contract. Data on energy prices published by the DTI is a good case in point. For example, four different categories of electricity prices to industrial and commercial users are published: price for small users, large users, very large users, and an average price. Energy-intensive industries, such as steel and aluminium, are reluctant to state their energy costs, which are further complicated if power is generated on site.

5. For such reasons of confidentiality, with regard to value as well as other data, such as input and output data for specific industrial processes, value chain analysis to identify for example waste disposal or Climate Change Levy costs will be a more powerful tool if performed internally to an industry.

A further limitation of both the MFA and VCA undertaken in this project is that the system boundaries have been defined as the UK boundaries. This has obvious advantages; however, both steel and aluminium are internationally traded commodities produced by global industries with complex international ownership structures. Many environmental impacts associated with the steel and aluminium production and use in the UK, for example the environmental damage associated with ore mining, are therefore outside the UK borders and have not been considered in this project.

9.2 Material Flow Analysis

Iron and steel

A high level of closure was achieved in the iron and steel MFA: recovered and landfilled metals accounted for about 90% of EOL metal emerging from use. The historic data recorded no marked overall upward or downward trend in the ultimate demand for iron and steel contained in goods, in the past 25 years. The ultimate demand was about 11-13 Mt per year. Of this demand, over 50% is currently met by imported goods (Section 3.4.6). This implies that iron and steel in use in the UK are likely to come from abroad rather than from domestic iron and steel plants. The imports of iron and steel contained in goods grew to 7 Mt per year in 2001, about two Mt more than the exports.

Despite fairly stable ultimate demand for iron and steel, the quantities of iron and steel scrap available are still growing due to the long service lives of goods containing iron and steel. About 10 Mt of EOL iron and steel scrap were released from use in 2001 in the UK, compared with 9.8 and 9.6 Mt in 1999 and 2000 respectively. Together with 1.3 Mt of prompt scrap arisings in 2001, this amounted to more than 11 Mt. Of this scrap, 4.8 Mt were exported and recycled abroad whereas 3.5 Mt were recovered and recycled domestically. A further 2 Mt ended up in landfill.

The recovery of iron and steel scrap arising in the UK thereby seems to be working relatively well in that about 70% of the scrap arisings is recovered and recycled. The analysis (Section 3.5.3) suggests that a significant part of the potential scrap loss originate from products like domestic appliances, hand tools, metal furniture and other products that are included among the new goods categories of metal goods, and electrical and mechanical engineering. This highlights the need for further material flow analyses of these specific sectors.

As for the recycling of iron and steel scrap, there has been a slow decrease in scrap consumption in UK iron and steel making. Primary iron and steel increasingly dominates the production. In 2001, about 75% of UK produced crude steel came from integrated steelworks (BF/BOFs), which produce steel from mainly virgin materials, and 25% from electric arc furnaces (EAFs), which produce steel from mainly scrap inputs. In the late 1970s and early 1980s, when the EAFs had the highest output, they supplied between 35 and 40 per cent of crude steel output.

The decline in scrap consumption is due to the decline in the number of operating EAFs, and therefore in UK scrap-reprocessing capacity. This has led to increasing exports of scrap over the years for recycling abroad. A reversal of the decline in EAF capacity would enhance the environmental performance of UK iron and steel-making.

Looking at the upstream iron and steel flows, it can be concluded that domestically produced iron and steel products were not able to meet the ultimate demand, as there were massive imports and exports across the borders. This implies that although the amount of iron and steel produced was higher than the amount of iron and steel needed in the downstream sector, the specifications of the products are not in line with the downstream demand. It is conceivable from the economic perspective that due to the global nature of the business the UK production could not economically produce all of the products that are required. In 2001, about 45% of domestically produced iron and steel products were different from those required by UK goods manufacturers and fabricators, and were destined to be consumed overseas. In addition, there is an increasing trend in imports of iron and steel products. The contribution of imports to the total consumption of iron and steel products increased from 20% in the 1970s to about 40-50% in the 2000s. This is partially due to the strength of the pound that makes it financially more attractive for UK goods manufacturers to import iron and steel products, and partially to the mismatch between domestic supply and demand in term of product specifications.

Around 15 Mt of iron and steel products from both domestic and foreign producers were delivered to UK goods manufacturers and fabricators in 2001.. In 2001, most of this iron and steel went into building and construction (26%), followed by other industries (20%), mechanical engineering (17%) and vehicles (17%). These four sectors currently consume 80% of the total deliveries of iron and steel products in the UK and have done so over the last 30 years. Similarly, the majority of iron and steel contained in goods going to use in the UK use are goods from these sectors.

The demand pattern of crude steel and pig iron is in line with the declining demand of iron and steel products. Production of the three iron and steel material categories all experienced considerable reduction before 1980 and then gradually stabilised after 1980, but again showed a declining trend during the past 5 years.

Putting UK crude steel material flows into the global context shows that UK production and consumption contributed to one sixtieth and one tenth of world and EU production and consumption respectively, whilst the per capita consumption was about half of the EU level and one and half times larger than the world average.

Aluminium

A high level of closure was achieved in the aluminium MFA: recovered, landfilled and dissipated metals accounted for about 99% of EOL aluminium emerging from use. The historic data recorded a remarkable growth in the ultimate UK demand for aluminium contained in goods during 1958-2001. There was only a slight deceleration of this growth in 2001, possibly due to the business recession starting in that year. The ultimate demand in 2001 was about 1 Mt per year. Of this demand, 60-80% was met by imported goods (Section 4.4.6). This implies that aluminium in use in the UK is likely to come from abroad rather than from domestic aluminium plants. The imports of aluminium contained in goods grew to 850 kt in 2001, about 350 kt greater than the exports.

In line with increasing ultimate demand for aluminium, the quantities of aluminium scrap available are constantly growing. About 622 kt of EOL aluminium scrap were released from use in 2001 in the UK, compared with 570 and 600 kt in 1999 and 2000. Together with 81 kt of prompt scrap arisings in 2001, this made up more than 700 kt. Of this scrap, up to 28% or 200 kt were exported and recycled abroad, whereas around 340 kt were recovered and recycled domestically. A further 160 kt ended up in landfill. The recovery of aluminium scrap arisings in the UK thereby seems to be working relatively well in that about 70-80% of the scrap arisings is recovered and recycled. The analysis (Section 4.5.3) suggests that a significant part of the potential scrap loss originates from products like EOL engineering goods, packaging and consumer durables. This highlights the need for further material flow analyses of these specific sectors.

As for recycling of aluminium scrap in the UK, there was growing output from remelters and refiners of semi-fabrications but a fairly stable output of unwrought products. Overall, the UK has seen a fast growing aluminium recycling industry. Despite the growth, there was more aluminium scrap recovered than can be recycled domestically, which led to large volumes of scrap exports. The industry also confirmed that there is enough capacity to deal with increasing scrap arising in the UK in the future as most of the secondary capacity is still not fully utilised (Alfed, 2003).

Looking at the upstream aluminium flows, domestically produced aluminium semi-fabrications and cast products have not been able to meet the ultimate demand as there have been massive imports and exports across the borders. Like iron and steel, this is partially due to the globalisation of the business and economic reasons. About half of the domestically produced aluminium products are different from those required by UK goods manufacturers and fabricators and are destined to be consumed overseas. Around 900 kt of aluminium products were delivered to UK goods manufacturers and fabricators in 2001 from both domestic and foreign producers. Most of this aluminium went into building and construction (30%) followed by transport (21%), packaging (21%) and engineering (13%). These four sectors currently consume more than 80% of the total supply of aluminium products in the UK and have done so over the last 30 years. Similarly, the majority of aluminium contained in goods going to use in the UK is also contained in goods from these sectors.

There have been violently fluctuating demand patterns for aluminium ingot, billets and slabs. These fluctuations were mainly caused by imports and exports. This reflects how the UK market has been influenced by the global aluminium industry. Despite unstable supply of ingots, billets and slabs, there has been a consistently growing trend in production of semi-fabrications and castings in the UK. This is due to large manufacturing and industrial stocks of ingots, billets and slabs that buffer the volatile supply (see Section 4.4.4), and the absence of any close link between the supply of ingots/billets/slabs and production of semi-fabrications and castings (Section 4.4.5).

Discussion

The fact that more iron, steel and aluminium containing goods are imported to than exported from the UK illustrates the general move of the UK towards an economy that increasingly depends on imported raw materials and goods to meet its material needs. However, this statement has to be made with caution. Firstly, it cannot be verified just by looking at the flows of one or two metals, as all materials used in society would need to be taken into account. Secondly, when looking at the entire supply chain, there is still a large volume of output from the upstream production, a large portion of which is not directly used in domestic downstream goods manufacturing but contributes to goods manufacturing in other countries.

Although the iron and steel sector is able to produce enough iron and steel products (and sometimes even more) to meet ultimate demand, the types of products produced do not align with demand in the downstream supply chain. Consequently, imported iron and steel products have increasingly made inroads into the UK market with competitive prices, which has led to erosion of the profit margin of UK producers and closures of several steel plants and mills. On the other hand, in the aluminium sector, most of the value added is created during semifabrication and casting or new goods manufacture. A significant part of these activities has taken place outside the UK. In other words, a large part of the UK domestic demand for these semifabricated and cast aluminium products and new goods has to be satisfied by imports. Moreover, although the aluminium sector does not produce sufficient quantities of aluminium products to meet domestic demand, it exports most products overseas. This implies a similar phenomenon to the iron and steel sector, which also leads to UK's heavy dependence on imported aluminium products and goods.

This pattern of production of trade, which agrees with findings from the UK Metals Industry Competitive Enterprise (MICE), is the result of globalised industries which take advantage of specialisation and economies of scale in different countries. However, another interpretation is that the metal industry has little knowledge of the real demand of end users (Taylor, 2001) and poor demand forecast practices. Although organisations belonging to both sectors have been actively improving their supply chain and business practices, few appear to have taken advantage of their geographical proximity to the domestic market by developing highly customised products and services to meet and match ultimate demand.

Future work

The study identified the quantities of iron, steel and aluminium in various forms that flow across each stage in the supply chains. It also inferred the amount of stocks of these metals contained in goods that are held in the use stage and their service life distribution at this stage, enabling estimation of the waste flows that report either to recovery/ recycling or to landfill. It does not consider the stocks of these metals that stay within each stage. In order to capture a holistic view of the iron, steel and aluminium material flows across the supply chains, further work should investigate the spatial and temporal distribution of these stocks and their economic and environmental implications.

Further study should also focus on managing and controlling the significant quantity of iron, steel and aluminium that is in the use stage, and planning to use it as a possible secondary resource. In order to do so, more information on composition on a time series basis, service life distribution, waste streams, contamination and geographic locations will be required. Obtaining this information, therefore, will allow forecasting of scrap arisings in the future in term of quality/quantities, grade and locations. In turn, this will further facilitate waste management and scrap recycling. A detailed mapping of the scrap arisings based on this further work is very important to the UK, given the pressure of the carbon dioxide emission target and the environmental advantages of recycled materials over virgin ones. Understanding of scrap arisings is also equally important given that the primary production and related activities of the country are no longer competitive in the increasingly globalised metal marketplace. Therefore, future competitiveness of the iron/steel and aluminium industries lies in the following two factors: on the one hand, good supply chain practices and development of niche markets; on the other hand, effective and efficient recycling and secondary production.

As this study is focused on material flows of only two types of metals within UK, it can be further expanded geographically and with more materials. Further study can be carried out for the same materials in other countries, therefore obtain a global view of the material flows of these metals. Simultaneously, further study can be carried out for other substantial materials of in UK economy to understand the progress that UK has made in sustaining its material metabolism. A prerequisite for doing so will be a harmonised categorisation of these materials and goods containing those materials. In addition, the time series dimension also needs an agreed way to reconcile data discrepancies caused by statistics method and change of classification systems.

9.3 Value Chain Analysis

9.3.1 Resource productivity and efficiency in the steel and aluminium industries

This project has examined resource productivity and efficiency trends in the iron and steel and aluminium industries, using time series data on material and energy inputs and outputs for measures of material and energy efficiency, and time series data on material and energy flows in combination with data on economic output for measures of material and energy productivity.

The analysis sheds light on broad resource productivity and efficiency trends in the two industries over the last two to three decades. Specifically, it has attempted to answer the following questions:

- Are the steel and aluminium industries improving their material efficiency, that is, are they creating more useful output with fewer material inputs;

- Are the steel and aluminium industries improving their energy efficiency, that is, are they creating more useful output with less use of energy;

- Are the steel and aluminium industries improving their material productivity, that is, are they creating more value with fewer material inputs;

- Are the steel and aluminium industries improving their energy productivity, that is, are they creating more value with fewer energy inputs; and

- Is any observed decoupling relative or absolute?

Iron and steel

Over the time period studied, the UK iron and steel industry has improved the efficiency with which it uses material and energy inputs substantially. These efficiency gains are absolute as well as relative. In relative terms, fewer inputs are needed per unit of output now compared to 30 years ago. Between 1968 and 2001, the amount of crude steel produced from a tonne of material inputs increased by 6% to 830 kg, and energy efficiency almost doubled, with one TJ of energy producing 53 tonnes of steel in 2001, compared with 27 tonnes in 1968. These improvements are associated with technological advances in casting processes and the take-up of continuous casting techniques, and improvements in stock management.

In absolute terms, there are now fewer material and energy inputs required in total by the UK iron and steel industry compared to 30 years ago. Inputs for crude steel production have decreased by 50% in the time period studied, to just over 16 Mt in 2001. Energy consumption for the iron and steel industry has decreased by 63.5%, to 260,000 TJ energy consumed in 2001. From an environmental perspective, these are positive findings, as environmental impacts depend on absolute levels of resource use.

The absolute decline in steel industry resource use is due to efficiency gains as well as the contraction of the industry, the output of which has declined by 29% in the time period studied, to 13.4 Mt of steel products in 2001. It is also indicative of the broader shift in the UK away from manufacturing toward a service economy.

In contrast with the resource efficiency indicators, resource productivity indicators (defined as value added per unit of resource use) show productivity declines over the period studied. The steel industry today generates less value per material and energy inputs compared to 30 years ago. Between 1973 and 2001, the value added (in real terms) per tonne of material inputs in crude steel production decreased by 82% to £29, and the value added per TJ of energy consumed in the iron and steel industry decreased by 61% to £3,800. The decline in value is also absolute, with the gross value added by crude steel production decreasing by 89% to £554 million in 2001. The reasons for and significance of this are discussed further below.

Economic labour productivity, measuring value added per worker, has fluctuated quite widely, with rapid productivity declines since 1995, although overall the trend seems to be moving upward. Value added per worker (in crude steel production) was just over £16,000 in 2001. However, material labour productivity shows constant improvements over the whole time period studied. Between 1979 and 2001, material output per worker increased by 75%, to 467 tonnes of crude steel per worker in 2001. It is therefore clear that while steel production has declined in the UK, the associated employment has declined more rapidly – by 84% between 1979 and 2001, to 29,000 employees in 2001.

Aluminium

Due to the lack of actual data on materials and energy consumption in UK aluminium production, clear resource efficiency trends are hard to establish and results should be treated with caution. No data exist on material inputs into aluminium production, other than the basic formula describing the conversion of bauxite into primary aluminium. Given that the conversion of bauxite to alumina is fixed by stoichiometry, primary material efficiency gains must be negligible.

Energy efficiency indicators were established with European average energy consumption figures for primary and secondary (refining and remelting) aluminium production, rather than with data on actual UK energy consumption. However, the results should give a good indication of broad trends in the industry. For primary aluminium, energy efficiency improved by 10% between 1980 and 2001, so that one TJ of energy produced 18.2 tonnes of primary aluminium in 2001. In the same time period, there has been a decline in output by 9%, to 340,800 tonnes of primary aluminium produced in 2001. Because of the efficiency gain and this decline in output, absolute energy consumption in primary production has decreased by 17% to 19,000 TJ in 2001. However, production has been growing rapidly since 1995 and it seems unlikely that relative energy efficiency gains will compensate for the growth in output.

The efficiency with which energy is used in secondary aluminium production has also improved. Energy efficiency improved by 11% between 1988 and 2001, to produce 128 tonnes per TJ energy consumed in 2001. However, production has grown significantly in this time period, by 63%, and the energy efficiency gains have therefore been insufficiently large to offset this growth. There has therefore been a net increase in energy use, by 47% to a total of 6,500 TJ energy consumed in 2001 by this part of the industry.

For aluminium production as a whole (combining primary and secondary aluminium production), there have been overall efficiency gains, which have been offset by the growth in total output. Energy use has therefore increased between 1988 and 2001. Energy efficiency increased by 47% to produce 46 tonnes of aluminium per TJ energy consumed in 2001. As output grew by 45% to almost 1.2 Mt, total energy consumption was up 15% to 25,000 TJ in 2001.

The analysis demonstrates the sensitivity of the industry, in terms of levels of energy efficiency and absolute energy use, to the relative proportions of primary and secondary aluminium production. Primary smelting uses about seven times as much energy as refining and remelting activities, according to the data analysed. The significant improvements in energy efficiency are positive, as is the growth of the industry; however, the total increase in energy consumption is less desirable from an environmental point of view.

In contrast with the energy efficiency indicators, resource productivity indicators show productivity declines over the period studied. It was not possible to create a material productivity indicator of the form value added per unit of material input for the aluminium industry, as no data on materials consumed were available. Data on outputs of semis and castings were therefore used to formulate a proxy material productivity indicator. This indicator showed wide fluctuations in what appeared to be a downward trend: the value added, in real terms, per tonne of aluminium output has decreased by 56% to £600 in 2001. Despite growth in material output, value added by the industry has also declined in absolute terms: the value added by the UK aluminium industry has decreased by 46%, to £416 million, between 1980 and 2001. Again, the reasons for and significance of this are discussed further below.

It was also not possible to create an energy productivity indicator for the aluminium industry, as the data on value added and the data on energy consumption referred to different parts of the industry. The energy consumption data refer to primary and secondary aluminium only, and exclude semifabrication and casting activities. However, the value of semifabrication and casting is included in the economic data. A proxy energy productivity indicator was constructed for purposes of broad trend illustration. This indicator shows a steady decline in value added per unit of energy consumed since 1995.

Economic labour productivity, measuring value added per worker, has fluctuated quite widely, in what appears to be a gradual upward trend. Value added per worker was about £35,000 in 2001. However, material labour productivity shows constant and dramatic improvements over the whole time period studied. Between 1980 and 2001, material output per worker almost tripled, to 58 tonnes of aluminium products per worker in 2001. Even though UK production of aluminium semis and castings has more than doubled between 1980 and 2001, the associated employment has declined by 56% in the same time period, to 12,000 employees in 2001.

Resource productivity and efficiency conclusions

The steel industry has improved its material efficiency somewhat in the time period studied, that is, it is creating more useful output with fewer material inputs. Due to the substantial contraction of the industry during the same time, there has also been an absolute decrease in the total amount of material inputs for crude steel production compared to the situation 30 years ago. It was not possible to create a material efficiency indicator for the aluminium industry as no data on consumption of material inputs exist, but as the conversion of bauxite to alumina is fixed by stoichiometry, material efficiency improvements for primary aluminium must be negligible. As aluminium output has increased in the UK, absolute resource requirements have therefore also increased.

There have been quite substantial improvements in the energy efficiency associated both with steel and aluminium production in the UK. Energy efficiency in steel production has almost doubled, and these efficiency gains in combination with a decline in production mean that absolute energy consumption for UK steel production is significantly less than it was 30 years ago. Energy efficiency in aluminium production has also increased substantially; however, output has also increased and therefore total energy requirements are larger now than 15 years ago. Also, the analysis revealed the sensitivity of energy efficiency and total energy consumption to the relative proportions between primary and secondary aluminium production in the UK, as the latter uses one seventh less energy according to the energy data analysed.

Currently, both primary and secondary aluminium production is growing rapidly in the UK, although secondary production seems to be increasing at a faster rate.

In contrast with the indicators of material and energy efficiency, which all show improvements, measures of material productivity (value added per unit of material input) and energy productivity (value added per unit of energy input) for both iron and steel production demonstrate declining trends; that is, the industries are now generating less value added per unit of primary resource use..

Economic labour productivity, measured by value added per worker, shows significant fluctuations over the time period studied. However, the trend seems to be gradually improving over time. Material labour productivity on the other hand, material output per worker, has improved dramatically for both iron and steel production.

It is interesting that, for both steel and aluminium, resource efficiency indicators demonstrate significant improvements over the time period studied, whereas resource productivity indicators, employing monetary output variables, demonstrate declines. This reflects the fact that prices of metals have fallen substantially in real terms over the last few decades. The price, in real terms, of steel fell by a factor of 4, and the price of aluminium almost halved, between 1974 and 2001.

The findings in this section raise important questions for the use of resource productivity indicators, involving monetary output measures, for examining trends relating to environmental impacts and resource use at the sectoral level. The products of sectors like steel and aluminium are globally traded commodities, subject to intense competitive pressures and, therefore, pressures to cut costs. Wages are a major element of costs and therefore there is a relentless drive to increase labour productivity, either by increasing output per worker, or by reducing employment while keeping output constant. It was seen above that labour productivity in both steel and aluminium has increased substantially.

However, wages are a major element of value-added as well as a major cost. If a sector's wage costs fall, permitting a fall in price, so will its value added, and this has happened with both steel and aluminium, as seen above. With sectoral resource productivity measured as sectoral value added per tonne of resources (either as input or output), sectoral resource productivity will decline. However, as seen above, this says nothing about the efficiency with which the resources have been used: the material and energy efficiency of steel production, and the energy efficiency of aluminium production, have all increased substantially over the past few decades.

For the economy as a whole, a resource productivity measures of Gross (National) Value Added per unit of material or energy use would still be a meaningful indicator, because the employment base remains the same (although this is not the case for individual sectors). Sectors that shed labour will be balanced by sectors that absorb it, so that the labour input of the economy as a whole will be unchanged by these shifts (assuming only transient unemployment), so that changes in total value added (a major part of which will be the aggregate of all wages in the economy) will provide an indication of the productivity of the labour force, and value added per unit of resource use will give a meaningful indication of the relative resource use to create that value added.

9.3.2 Value chain mapping

Iron and steel

Combining data on the values of different iron and steel material categories with data on their flows through the UK economy enabled a mapping of the UK iron and steel value chain to be drawn. It is set out in summary in Table 9.1. All data refer to 2001.

There is no longer any iron ore mined in the UK, and in 2001, the value of imports was just over £300 million in 2001. Like many other minerals, the price of iron ore has experienced a dramatic price decline in real terms.

Imports and exports of pig iron are very small in both material and value terms, with the value of imports totalling less than £30 million, and the value of exports less than £4 million. Exports of pig iron virtually disappeared after 1995; however, 2001 saw small exports but with a very high average monetary value per tonne compared to imported pig iron. The output of pig iron for the domestic market is valued at almost £600 million.

Imports and exports of crude steel totalled around £120 million and £220 million respectively. To estimate the values for crude steel output from the integrated route and the electric arc route, a more detailed level of breakdown on material flows than that used in the material flow analysis is necessary. The integrated, or BOF, route produces a negligible amount of alloy steels, so all output is assumed to be carbon steel. Using a value of £170/tonne for this material sub-category, the total output from this route is valued at £1.75 billion.

The EAFs, which use iron and steel scrap rather than iron ore as input, produce alloy steels in addition to basic carbon steels. The high value of these means that while the EAF output in material terms is considerably smaller than the output from the integrated route, the difference in value is not so large. The total value of output from the EAF route in 2001 was £1.11 billion. On a pound per tonne basis, the output from the EAFs therefore has an average of £340/tonne.[36]

UK production of steel products is worth over £6.2 billion, and the value of imports and exports are also considerable: £2.9 and £2.6 billion respectively. International competition and cheap imports help explain the rising trend in imports since the early 1990s, as well as the decline in exports in the last few years.

The large volume of end-of-life scrap arisings has a total value of about £500 million, and the smaller amount of prompt scrap arisings is valued at £125 million. Exports of scrap are growing rapidly, and represent a value of £385 million in 2001. Scrap imports are much smaller; however, due to the much higher average price paid for

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[36] The very high value of the EAF output is due to the UK focus on the production of specialty steels rather than basic steels in the EAFs.

these materials, imports are actually worth more than the exports, at £479 million. Unfortunately, the trade statistics on scrap do not offer any detail on the types of scrap traded, but the imports are assumed to be specialty grades of high-value scraps.

Finally, while most of the iron and steel that arises as scrap is being recovered through recycling in the UK or, as is increasingly the case, exported for recycling elsewhere, a great amount is being sent to landfill. The 2 Mt of iron and steel material contained in waste being sent to landfill in 2001 are estimated at a cost of £56 million. This cost falls primarily on local authorities throughout the UK, which have limited budgets. Also, waste disposal costs are increasing as the landfill tax is expected to eventually reach £35/tonne, at which level (assuming no change in gate fee) the amount of iron and steel disposed of would cost just over £102 million.

The materials also represent a potentially valuable source of raw materials for the iron and steel industry, and a potential income for those who could recover them. If the landfilled material could be recovered, and sold at the price of old steel scrap (£50/tonne), it would have a value of £100 million. The profitability of recovery depends on many factors: the rise in landfill tax; the landfill reduction targets to which local authorities are committed; and the steel packaging recovery targets set by the packaging regulations. These will increase the extent to which scrap collection, sorting and preparation are carried out.

Table 9.1 Iron and steel summary table[1]

Material category		Domestic production		Imports		Exports		Net Imports = Imports - Exports	
		Weight	Value	Weight	Value	Weight	Value	Weight (kt)	Value (million)
Iron ore				15,112	£302.2			15,112	£302.2
Pig iron		9,870	£592.2	160	£28.8	7	£3.6	153	£25.2
Crude steel	BOF	10,271	£1,746.1	393	£121.8	751	£217.8	-358	-£96.0
	EAF	3,272	£1,110.8						
Steel products		14,814	£6,221.9	7,697	£2,924.8	6,089	£2,557.4	1,608	£367.4
Scrap	new	1,383	£124.5	171	£478.8	4,818	£385.4	-4,647	£93.4
	old	10,013	£500.7						
Scrap to landfill		2,000	-£56.0						

The final column displays net imports (imports – exports) in both weight and value terms for the different iron and steel material categories. In weight terms, there was a trade surplus (exports exceed imports) for crude steel and scrap. However, in value terms, there was a trade surplus only for crude steel, due to the very high value of scrap imports. Net imports of steel in steel products are about 11% of domestic steel production incorporated into products.

Aluminium

Combining data on the values of different aluminium material categories with data on their flows through the UK economy enabled a mapping of the UK aluminium value chain to be drawn. It is set out in summary in Table 9.2. All data refer to 2001.

As there is no longer any smelter-grade alumina production in the UK, there were no bauxite imports for aluminium production. The value of smelter-grade alumina imports was about £127 million in 2001.

Imports and exports of aluminium in 2001 totalled around £380 million and £290 million respectively. For domestic production, the value of the output of primary ingot is estimated at £344 million, refiners' ingot at £252 million, and remelters' ingot at £591 million – or a total of almost £1.2 billion. Remelter's ingot is usually not sold but internally transferred, although the value is displayed for purposes of illustration.

The value of the trade in semifabricated aluminium products is considerable, with imports worth £777 million and exports £385 million. The value of the domestic production of semis and castings is estimated at almost £1.9 billion. It is clear that the production of semis and castings is a very high value adding activity, the demand for which is increasingly met through imports. In 2001, imports met 46% of domestic demand (production + imports – exports) in material terms, but only 34% in value terms.

The large volume of end-of-life scrap, almost 700,000 tonnes, and the high value of aluminium scrap, means that there is significant value even at this stage of the chain – almost £440 million worth of old scrap arises from the consumption and use stage. Another £74 million worth of new scrap arises from the various aluminium consuming manufacturing sectors. Scrap imports in 2001 were worth around £74 million, and exports totalled around £146 million. Imports of aluminium scrap have increased substantially since the early 1990s. However, exports have also increased greatly over the last two decades, and while these exports represent significant value as export earnings, the outflows of these materials from the UK also represent a loss of the energy that is embodied in the scrap, in addition to the obvious loss of the materials themselves.

Finally, while most of the aluminium that arises as scrap is being recovered through recycling in the UK or, as is increasingly the case, exported for recycling elsewhere, a substantial quantity is still being sent to landfill. About 160,000 tonnes of aluminium contained in waste was sent to landfill in 2001, at an estimated cost of £4.5 million. This cost falls primarily on local authorities across the UK, which have very restricted budgets. Also, waste disposal costs are increasing as the landfill tax is expected to eventually reach £35/tonne of landfilled waste, at which level (assuming no change in gate fee) the amount of aluminium disposed of would cost over £8 million.

The aluminium sent to landfill also represents a potentially very valuable source of raw materials for the aluminium industry, and a potential income for those who could recover them. If the landfilled material could be recovered, and sold at the price of old aluminium scrap (£650/tonne), it would have a value of £104 million. The profitability of recovery depends on many factors: the rise in landfill tax; the landfill reduction targets to which local authorities are committed; and the aluminium packaging recovery targets set by the packaging regulations. These will increase the extent to which scrap collection, sorting and preparation are carried out.

Table 9.2 Aluminium summary table

Material category		Domestic production			Imports			Exports			Net Imports = Imports - Exports		
		Weight (kt)	Value (million)	CO_2 (kt)	Weight (kt)	Value (million)	CO_2 (kt)	Weight (kt)	Value (million)	CO_2 (kt)	Weight (kt)	Value (million)	CO_2 (kt)
Bauxite*					163	£8.2							
Alumina					704	£126.7	943				704	£127	943
Aluminium	primary	341	£344.2	3,385	347	£381.6	1,113	263	£292.3	845	84	£89	268
	refiners' ingot	249	£251.6	199									
	remelters' ingot	585	£591.2	185									
Semi-fabricated products	rolled products	385	£935.0	298	405	£777.2	308	219	£385.3	167	186	£392	142
	extruded products	177	£309.9	160									
	castings	129	£621.8	68									
Scrap	new	81	£74.3	83	110	£73.8	12	208	£145.8	23	-98	-£72	-11
	old	672	£436.7										
Scrap to landfill		160	-£4.5	na									

Note: Data on CO_2 equivalent emissions for alumina from SimaPro, for scrap (referring to the transport emissions generated in their collection) from Davis (2004), all other EAA (2000). For imports of aluminium and semifabricated products, the same proportions that exist in the UK in terms of production of sub-categories have been assumed.

*Bauxite imports are not for aluminium production, displayed only for illustration purposes.

Table 9.2 includes, in addition to weight and value data, estimates of CO_2 emissions associated with the various material categories. These estimates should be treated with caution, but can nonetheless give an idea of the order of magnitude of greenhouse gas emissions associated with the different stages in the aluminium production and use chain. It can be seen that the great majority of CO_2 emissions – over 3.3 million tonnes – arise from the primary production of aluminium, while CO_2 emissions from secondary production amount to 384 kt. The emissions data for these processes include the indirect greenhouse gas emissions associated with electricity generation and transmission. CO_2 emissions from the production of semi-fabricated products amount to 526 kt, although these are direct emissions only.

The final column displays net imports (imports – exports) for the different aluminium material categories. In terms of weight, value and greenhouse gas emissions, there was a trade surplus (exports exceed imports) only for aluminium scrap. Greenhouse gas emissions associated with UK aluminium production and use are largely associated with domestic production, with net imports contributing to around one third (1,342 kt) of the CO_2 emissions from domestic manufacture (4,378 kt).

9.3.3. Packaging waste

It seems likely that the UK system of implementing the Packaging Regulations through the tradable mechanism called Packaging Recovery Notes (PRNs) has generally contributed to an increase in the recycling of packaging waste which is cost effective. The PRNs are bought by the companies that have recycling and recovery obligations from accredited reprocessors or accredited incinerators of packaging waste, and used as evidence that the companies have complied with their recycling/recovery obligations. With respect to packaging in the household waste stream, the recycling system is largely paid for by tax-based funding of local authority collections.

However, another reason why UK compliance costs with the Packaging Directive have appeared low is that, compared to some other European countries, the recovery rate is still modest – there has been an increase in collection of around 11% of all packaging waste, and an increase in reprocessing of around 8%.

The role played by wood waste packaging in meeting EU recycling targets has been much more significant than was anticipated. Although recovery of wood packaging received among the lowest levels of financial support (in unit terms), it contributed over 40 per cent of the growth in recycling. Had this not occurred, it is doubtful that compliance with the targets in the 1994 Directive would have been possible without a substantial increase in PRN/PERN values for all the other materials, perhaps doubling the compliance costs incurred by obligated businesses.

The lack of a viable mechanism for sanctioning failing compliance schemes has led to lower levels of demand for PRNs, reducing the marginal costs of packaging recycling and recovery in the UK, and hence, the prices paid for PRNs. The fluctuations in the PRN price have not helped planning for the development of either the collection or reprocessing infrastructure. PRN prices seem strongly driven by recycling targets. It seems that unless targets continually increase, PRN prices fall back, which hinders the smooth development of the collection and reprocessing infrastructure.

A positive conclusion from the price sensitivity of PRNs to targets is that, in the industrial and commercial sector at least, it seems that once collection and reprocessing infrastructure is in place, reduced levels of subsidy are required to keep it operational. It is not yet known whether this would also apply to the household sector, but it seems likely to be the case.

The volume of steel and aluminium packaging in household waste, the increasing targets for recovering packaging waste in the future, and pressures to recover other waste streams from households, make it both desirable and necessary for household waste to play a larger part in meeting the packaging waste recovery targets in the future than it has in the past. This means that local authorities are going to need greater levels of recycling finance. To be consistent with the producer responsibility principle, this finance should be provided by the packaging industry (and therefore the cost passed on in the cost of the packaging) rather than by the taxpayer.

These conclusions suggest the following recommendations in respect of steel and aluminium to ensure that the recycling target for 2008 is met:

- In order to facilitate the steady and predictable development of recycling infrastructure, recycling targets should be set to increase on an annual basis. It would seem prudent to set the targets slightly higher than the statutory minima. Defra has set targets to increase on an annual basis to 2008, but these targets are still at the minimum level permitted by European rules so that there is little room for the kind of miscalculations and data problems that have occurred in the past.

- To ensure that PRNs maintain the price necessary to develop new recycling activities, there should be sanctions for compliance schemes (passed on to their member obligated producers) that fail to meet their obligation to purchase PRNs. Defra did indeed announce that scheme operators would henceforth be legally responsible for discharging their recycling obligations, and would be liable for penalties if they failed to do so.

- To apply the concept of producer responsibility to the household waste stream, the packaging industry should provide increased funds to local authorities (LAs). To give an incentive to LAs to collect packaging waste (of all kinds, not just steel and aluminium) from households, they could be paid a premium price for such waste by reprocessors , funded out of PRN revenues. This would in turn require a higher PRN price, which would incentivise packaging producers to be more efficient in their use of packaging.

- It seems likely that the most efficient resource recovery infrastructure, and the one best suited to give effect to the proximity principle, would be integrated local facilities which handled both commercial and industrial waste along with municipal waste. This would enable economies of scale in waste handling to be achieved from the waste from a relatively small area. The Government should provide incentives, perhaps out of landfill tax revenues, for the creation of these integrated local waste management facilities, from which the recovery of all materials ending up as packaging waste could be maximised irrespective of their source.

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ABBREVIATIONS

Alfed	Aluminium Federation
CES	Centre for Environmental Strategy
EAA	European Aluminium Association
EOL	End-of-life
HMCE	Her Majesty's Customs and Excise
IISI	International Iron and Steel Institute
ISSB	Iron and Steel Statistics Bureau
kt	kilotonne (1,000 tonnes)
Mt	megatonne (1,000,000 tonnes)
OEA	Organisation of European Aluminium Refiners and Remelters
PSI	Policy Studies Institute
PRN	Packaging Recovery Note
ProdCom	PRODucts of the European COMmunity
TJ	Terajoule
WBMS	World Bureau of Metal Statistics

APPENDICES

Appendix 2.1 Summary of Theory of Residence Time Distributions

An entire branch of chemical engineering science, that of chemical reaction engineering, relies on analysis of the distribution of the time spent in a confined volume, usually a chemical reactor, by material flowing through that volume. Formally, analysis of the distribution of service lives of products is exactly the same as analysis of the residence time of chemicals in a reactor. The seminal analysis is fifty years old (Danckwerts, 1953) and the topic is now an integral part of degree programmes in chemical engineering and is covered in undergraduate texts (e.g. Levenspiel, 1972). Rather than develop an apparently new analytic approach, the theory and the conventional notation of residence time theory has been employed in this work. The development is set out, however, in MFA terms rather than in terms of chemical reactor theory.

Consider products leaving their use phase at the end of their service life. The fraction of the End-of-Life (EOL) products which were in use for times from t to $(t+dt)$ is

$$Edt$$

The function $E(t)$ is known as the residence time distribution, RTD. Necessarily

$$\int_0^\infty Edt = 1$$

The fraction of the EOL products which have been in use for time t_1 or less is

$$\int_0^{t_1} Edt$$

while the fraction which has been in use for more than time t_1 is

$$\int_{t_1}^\infty Edt = 1 - \int_0^{t_1} Edt$$

The form of the RTD function $E(t)$ describes the distribution of residence times amongst products at their end-of-life. If all products are in use for exactly the same time, then $E(t)$ takes the form of a delta function, i.e. a "spike". In chemical reactor theory, this idealised case is usually termed *plug flow*, with all fluid elements moving together through the reactor. At the opposite extreme is the case where the products currently in use have equal probability of being scrapped. In chemical reaction engineering, this case correspond to ideal complete mixing in the reactor; in MFA it is sometimes, confusingly, termed a *leaching model*. The RTD function takes the form

$$E = 1 - \exp(-t/\bar{t}) \qquad (1)$$

where $\bar{t}$ is the *mean service life* (or mean residence time in the case of a chemical reactor).

Real distributions of service lives can be described by functions intermediate in form between a delta function and equation (A.1). The mean service life is

$$\bar{t} = \int_0^\infty tEdt \tag{2}$$

and the variance of service lives is

$$\sigma^2 = \int_0^\infty (t - \bar{t})^2 Edt = \int_0^\infty t^2 Edt - \bar{t}^2 \tag{3}$$

Other functions describing product ages can be defined, and may be useful for other purposes. The *F* function describes the proportion of EOL products which have been in service for time *t* or less. If the stock of products in use is constant (or, in practice, if the variation in stock is small compared to the rate of products entering service) then the *F* and *E* functions are related by

$$F(t_1) = \int_0^{t_1} E(t)dt \tag{4}$$

and

$$E(t) = dF / dt \tag{5}$$

Although not used here, these relationships could be applied to interpret observations of the service lives of EOL products.

Danckwerts (1953) also defined the *I* function, which in MFA reoresents the distribution of the ages of products currently in use. The function *I(t)* is a distribution like *E(t)* but, whereas *E* may be termed the *exit* age distribution, *I* is the *internal* age distribution. Again for the case where the stock of products in use can be taken as constant,

$$I(t_1) = [1 - F(t_1)] / \bar{t} \tag{6}$$

$$= [1 - \int_0^{t_1} E(t)dt] / \bar{t} \tag{7}$$

The average age of products in use clearly differs in general from the average age of products leaving use at their EOL. It is given by

$$\bar{\theta} = \int_0^\infty \theta \ I(\theta)d\theta \tag{8}$$

$$= \frac{1}{\bar{t}} \int_0^\infty \theta \ [1 - F(\theta)]d\theta \tag{9}$$

Again, equations (A.6) to (A.9) have not been used here, but they could be useful in relating the age distribution of goods-in-service to EOL products.

Equations (A.1) to (A.9) refer to the case where the residence time distribution is described by continuous functions. In the present analysis, as in most MFA work, discrete time intervals are used - *Δt*, where *Δt* is one year in this case. Interval number *l* (i.e. year *l* from the start of the time series in this work) covers the period from *(l-1)Δt* to *lΔt*. Products entering service in interval *l* are associated with the mid-point of that period, i.e. mid-year in the present work. Similarly products reaching EOL in interval m are associated with the mid-point of that period, so that if they entered service in interval *l* their service life is discretised as *(m-l)* periods. The fraction of EOL products which were in use for *k* time periods is then

$$E_k = \int_{(k-\frac{1}{2})\Delta t}^{(k+\frac{1}{2})\Delta t} E(t)dt \qquad (10)$$

Provided that *Δt* is sufficiently small compared with the mean service life, $\bar{t}$, it is usually adequate to approximate E_k as $E(k\Delta t)\Delta t$.

The discretised forms of the *F* and *I* functions are

$$F_k = \sum_{l=1}^{k} E_l \qquad (11)$$

$$I_k = [1 - F_k]\Delta t / \bar{t} \qquad (12)$$

The mean and variance of service life are related to E_k by:

$$\bar{t} = \sum_{k=1}^{\infty} t_k E_k = \Delta t \sum_{k=1}^{\infty} k E_k \qquad (13)$$

$$\sigma^2 = \sum_{k=1}^{\infty} (t_k - \bar{t})^2 \; E_k = \sum_{k=1}^{\infty} t_k^2 E_k - \bar{t}^2 = \Delta t^2 \sum_{k=1}^{\infty} k^2 E_k - \bar{t}^2 \qquad (14)$$

For the case where the number of units of product or mass of material in service can be taken as constant, it is a general result (Danckwerts, 1953) that the mean service life, $\bar{t}$, is given by the stock in use divided by the rate of entry into use of new products or material. For the discretised case, if the stock comprises mass *M* and the material flux into use is m per year, then the mean service life is simply *M/m* years.

Appendix 3.1 Iron and steel related SIC sectors

Table 1 Iron & steel manufacturing industries

SIC	Description
271	Manufacture of basic iron and steel and of Ferro-alloys (ECSC)
272	Manufacture of tube
273	Other first processing of iron and steel and production of non-ECSC Ferro
27.51	Casting of ion
27.52	Casting of steel

Table 2 The 9 categories of iron and steel goods manufacturing sectors

Commodity group	Subgroup	SIC	Description
Mechanical engineering and plant	Machinery and equipment	28.22	Manufacture of central heating radiator and boilers
		29.11	Manufacture of engines and turbines, except aircraft, vehicle and cycle engine
		29.12	Manufacture of pumps and compressors
		29.13	Manufacture of taps and valves
		29.2	Manufacture of other general purpose machinery
		29.3	Manufacture of agricultural and forestry machinery
		29.4	Manufacture of machine tools
		29.5	Manufacture of other special purpose machinery
	Other mechanical engineering	28.5	Treatment of coating of metals, general mechanical engineering
		29.14	Manufacture of bearings, gears, gearing and driving elements
		29.6	Manufacture of weapons and ammunitions
	Other industrial plants	28.3	Manufacture of steam generators, except central heating hot water boilers
Electrical engineering	Domestic electrical appliance	29.71	Manufacture of electric domestic appliances
	other electrical engineering	30	Manufacture of office machinery and computers
		31.1	Manufacture of electric motors, generator and transformers
		31.2	Manufacture of electricity distribution and control apparatus
		31.3	Manufacture of insulated wire and cables
		31.4	Manufacture of accumulator, primary cells and primary batteries
		31.5	Manufacture of lighting equipment and electric lamps
		31.62	Manufacturer of electrical equipment not elsewhere classified
		32	Manufacture of radio, television and communication equipment and apparatus
Shipbuilding	Shipbuilding	35.1	Building and repairing of ships and boats
Vehicles	Vehicles	31.61	Manufacture of electrical equipment for engines and vehicles not elsewhere classified
		34	Manufacture of motor vehicles, trailers and semi-trailer, caravans
	Other transport	35.2	Manufacture of railway and tramway locomotives and rolling stock
		35.3	Manufacture of aircraft and spacecraft
		35.4	Manufacture of motorcycles and bicycles
		35.5	Manufacture of other transport equipment not elsewhere classified

Structure steelwork &civil engineering	Structural steel work	28.1	Manufacture of structure metal products
	Construction	45	Construction
Can and metal boxes	Cans &metal boxes	28.72	Manufacture of light metal packaging
Metal goods	Metal furniture	36.1	manufacture of furniture
	Other metal goods	28.6	Manufacture of cutlery, tools and general hardware
		28.74	Manufacture of fasteners, screw machine products, chains and springs
		28.75	Manufacture of wire products
		29.72	Manufacture of non-electric domestic appliances
Boilers, drums& vessels	Boilers &associated plants	28.3	Manufacture of steam generators, except central heating hot water boilers
	Vats, tanks and drums	28.21	Manufacture of tanks, reservoirs and containers and metal
		28.71	Manufacture of steel drums and similar containers
Other industries	Coalmining	10.1	Mining and agglomeration of hard coal
		10.2	Mining and agglomeration of lignite
	Oil &gas extraction	11	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction excluding surveying
	Wire drawing	27.34	Wire drawing
		28.73	Manufacture of wire products
	Forging &stamping	28.4	Forging, pressing, stamping and roll forming of metal, powder metallurgy
	Cold forming	27.33	Cold forming or folding
	All other consumers	all other codes	

Appendix 3.2 Trade classifications of goods containing iron and steel

Trade statistics are given according to SITC (Standard Industry Trade Classifications) codes. These classifications have been revised three times since 1968, only the latest classification codes (SITC Rev.3) are shown here. In the material flow analysis, the classifications valid for the particular year data have been collected have been used. Data on product groups that contain iron and steel have been collected; the product groups are given in table 1 grouped into the nine categories applied in the material flow analysis.

Source: Overseas Trade Statistics - UK Trade with the EC and the World 1998, HM Customs and Excise, UK Tariff and Statistical Office.

SITC code	
	Mechanical engineering
721	agricultural machinery (excl. tractors) and parts thereof
722	tractors (O/T those of 744)
73	metalworking machinery
725	paper mill and pulp mill machinery
724	textile and leather machinery, and parts thereof, NES
726	printing and bookbinding machinery
727	food-processing machines (excl. domestic)
728	other machinery, NES
74	general industry machinery and equipment, NES
712	steam turbines and other vapour turbines, and parts thereof, NES
713	internal combustion piston engines, and parts thereof, NES
714	engines and motors (O/T those of 712, 713 & 718); parts, NES, of these engines and motors
716	rotating electric plant and parts thereof, NES
718	other power generating machinery and parts thereof
	Electrical engineering
697.31	domestic cooking appliances (eg cookers) & plate warmers, non-el., of I or S
697.32	domestic stoves, grates & similar non-el. space heaters, of I or S
697.33	parts of I or S, of the appliances of .31 and .32
76	telecommunications and sound recording and reproducing apparatus and equipment
77	electrical machinery, apparatus and appliances, NES and electrical parts thereof
75	office machines and automatic data processing machines
	Shipbuilding
	(only reported in its own category in the first classifications (R0), now reported in category 79)
	Vehicles
781	motor cars and other m/vehicles principally for transport of persons (O/T public transport v.)
782	motor vehicles for the transport of goods and spec. purposes vehicles
783	road motor vehicles, NES
784	parts and accessories of motor vehicles

785	motor cycles (incl. mopeds) and cycles, motorised and non-motorised
786	trailers and semi-trailers; other vehicles not mech. propelled
79	other transport equipment (incl. railway vehicles, aircraft, ships etc)
	Structural steelwork, building and civil engineering
691.1	structures (O/T pre.fab. buildings) & parts of I or S; plates shapes etc, PRD for structures, of I/S
694.1	nails, tacks, drawing pins & similar articles, of I or Steel (incl. those with heads of other material except Cu)
694.2	screws, bolts, nuts, screw hooks, rivets, cotters, cotter-pins, coach screws & similar articles of I or S
	Metal goods
695	tools for use in the hand or in machines; eg saws, files, spanners, hammers, chisels, drilling tools, knives etc
696	cutlery incl scissors, razor blades etc
697.41	household articles and parts thereof, NES, of I or S
697.44	I or S wool; pot scourers and scouring or polishing pads, gloves and the like, of I or S
697.51	sanitary ware and parts thereof, NES, of I or S
697.8	household appliances, decorative articles, frames and mirrors, of base metal, NES
699.1	locksmiths' wares, safes, strong boxes, etc and hardware, NES, of base metal
699.2	chain and parts thereof, of I or S
699.31	sewing and knitting needles, crochet hooks etc, of I or S
699.32	safety pins and other pins, of I or S
699.41	springs and leaves for springs, of I or S
699.5	miscellaneous articles of base metal; eg bells, signs, electrodes etc.
699.6	articles of I or S, NES; eg anchors, cast articles, wire etc.
821.3	furniture, NES, of metal
693.11	stranded wire, ropes, cables, plaited bands, slings and the like, of I or S, not electrically insulated
693.2	barbed wire of I or S, twisted hoop/single flat wire, barbed or not, of a kind used for fencing
693.51	cloth, grill, netting & fencing, of I or S wire; expanded metal of I or S
	Cans and metal boxes
	(Not reported)
	Boilers, drums and other vessels
812.1	central heating boilers and radiators, air heaters & hot air distributors, not ele. heated of I or S
711	steam or other generating boilers, super-heated water boilers, & aux. plant for use therewith
692.11	reservoirs, tanks, vats and similar containers, of I or S, >300 litres
692.41	tanks, casks, drums, cans, boxes & similar CTR of I or S, < 300 litres, O/T for compressed or liquefied gas
692.43	containers of I or S for compressed or liquefied gas
	Other industries
723	civil engineering and contractors' plant and equipment

Appendix 3.3 Waste to landfill in the UK

Type	Year	Tonnes	Source	Comment
			England	
Municipal waste	2000/ 2001	22300000	http://www.defra.gov.uk/environment/statistics/wastats/mwb0102/wbch01.htm#wbch01landfill	2000/2001 corresponds to the financial year: 1 April 2000 to 31 March 2001, (tonnage out of which 4 400 000 are from civic amenity sites)
Industrial and commercial, steel	1998/ 1999	30000	Personal communication Alan Bell at the Environment Agency, tel: 01454 624337	Data from survey of industrial and commercial sector in England and Wales, does not include construction and demolition
Industrial and commercial, iron	1998/ 1999	13600	Personal communication Alan Bell at the Environment Agency, tel: 01454 624337	Data from survey of industrial and commercial sector in England and Wales, does not include construction and demolition
Industrial and commercial, aluminium	1998/ 1999	23000	Personal communication Alan Bell at the Environment Agency, tel: 01454 624337	Data from survey of industrial and commercial sector in England and Wales, does not include construction and demolition
			Wales	
Municipal waste		1526989	http://www.wales.gov.uk/subienvironment/content/survey/msw-e.pdf	tonnage out of which 269 641 are from civic amenity sites
			Scotland	
Industrial, construction & demolition, commercial	2000	8700000	Key Scottish Environmental statistics http://www.scotland.gov.uk/library5/environment/kses03-07.asp	
Household		2500000		
			Northern Ireland	
			found none	

Percentage of municipal waste that is ferrous metal according to Barton (1987): 7%
Percentage of municipal waste that is non-ferrous according to Barton (1987): 0.6%, assume 0.5% to be aluminium
Assume that 1% and 0.1 percent of Scottish industrial waste is I&S and Al respectively

Total UK iron and steel waste going to landfill in 2001	1973489 tonnes	**~2 Mt**
Total UK aluminium waste going to landfill in 2001	163335 tonnes	**~160 000 tonnes**

Appendix 3.4 Sensitivity analysis with consideration of stock level

To examine the sensitivity of the model to the industrial and commercial stock (ICS), we assume that:

Sn	The amount of iron and steel contained in the ICS of new goods in the system in year *n*,
SLn :	The ICS level in year *n,* expressed as Sn divided by actual delivery of iron and steel products to the downstream manufacturers from the iron and steel sector (eg. the amount of iron and steel contained in a new goods stock is about 10% of the actual delivery from the iron and steel sector to the new goods manufacturing sector, then the SLn of that new goods is 10%)
Dn	Delivery from iron and steel sectors to downstream new goods manufacturing sectors in year *n*
$SUPPLYn$	The available supply to the end-users in year n, which is Dn plus stock that is left from the previous year *n*
Tn	The actual delivery of new goods containing iron and steel to the end users in year *n*, which is $SUPPLYn \times (1 - SLn)$

So in year 1 of our study, the available supply to the end users:

$SUPPLY1 = D1 + S0$ Where $S0$ is the stock left from the previous year and the actual delivery to the end users can be expressed as

$$T1 = (D1 + S0) \times (1 - SL1)$$

As there is no data of the ICS stock in the first year of our study, we assumed $S0$ is zero, therefore

$$T1 = D1 \times (1 - SL1) \qquad (1)$$

$$S1 = D1 \times SL1 \qquad (2)$$

Then for year two,

$$T2 = (D2 + S1) \times (1 - SL2) \qquad (3)$$

Use *(2)* and (3) together then

$$T2 = (D2 + D1 \times SL1) \times (1 - SL2) \qquad (4)$$

Following the same logic, then in any of the year n, the actual delivery to end users are

$$Tn = (Dn + \sum_{i=1}^{n-1} (Di \times \prod_{j=1}^{i} SLj) \times (1 - SLn) \qquad (5)$$

With the modified actual delivery Tn from this analysis, the scrap arisings are then modelled with Weibull lifetime distribution. Figure 1 below gives a graphic illustration of the stock issue.

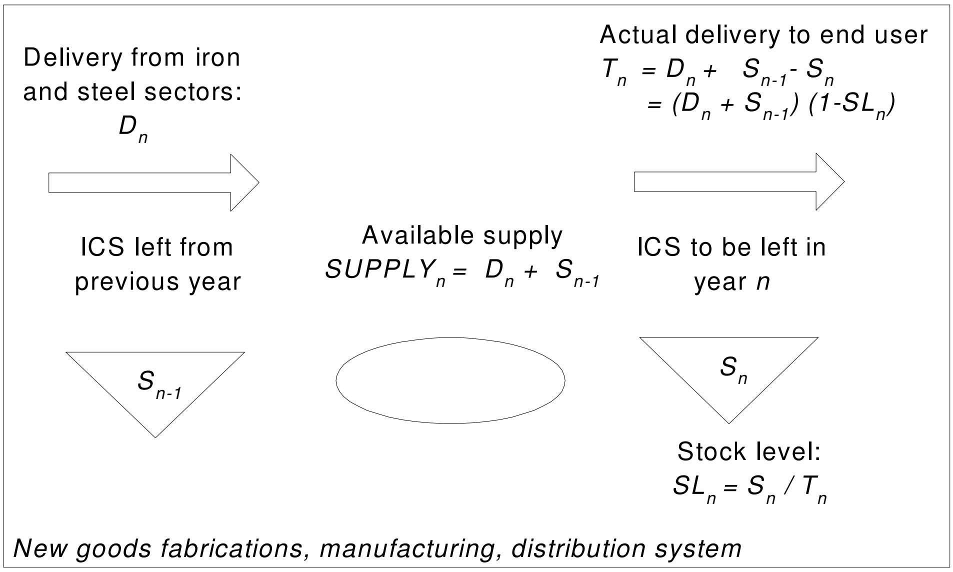

Figure 1 Stock issues in modelling scrap arisings

However, there are few records of the stock level in mass term in the literature whilst there are many in economic terms (Taylor, 2001, Hines, 2000). The economic term stock level is therefore used as a rough equivalent to mass term stock level. This study uses Waters' (1997) stock and GNP ratio between 1975-1990 for the stock level in all the 9 sectors, while using DTI manufacturing sectors stock survey results as stock levels for 1991-2001 (Table 1). The study also assumes the same stock levels for both iron/steel and aluminium.

Table 1 Stock level of new goods over the years

1949	60%	1960	43%	1971	38%	1982	32%	1993	12%
1950	60%	1961	42%	1972	36%	1983	31%	1994	12%
1951	55%	1962	42%	1973	38%	1984	29%	1995	12%
1952	51%	1963	41%	1974	41%	1985	28%	1996	12%
1953	48%	1964	41%	1975	38%	1986	27%	1997	12%
1954	46%	1965	41%	1976	37%	1987	26%	1998	12%
1955	46%	1966	41%	1977	38%	1988	25%	1999	12%
1956	45%	1967	40%	1978	37%	1989	23%	2000	12%
1957	44%	1968	40%	1979	39%	1990	20%	2001	12%
1958	43%	1969	40%	1980	34%	1991	12%		
1959	42%	1970	40%	1981	33%	1992	12%		

Appendix 3.5 Iron and steel time series data

Material iron ore **Thousand tonnes** **Process:** Blast furnace, steeling making

	Beginning stock	Flux in (Import)	Produced/Extracted	Flux out (export)	Used in blast furnace	From Import	From Home	Used in steel making	recycled	Disposal	Final stock
1968											
1969		18153	12298	0	30879	18567	12312				
1970		19923	12018	0	32259	20378	11881				
1971		17349	10228	0	27858	17730	10128				
1972		17451	9049	0	27031	17850	9181				
1973		21440	7105	0	28952	21888	7064				
1974		18270	3602	0	22519	18568	3951				
1975		15713	4490	0	20714	16005	4709				
1976		18637	4582	0	24031	19039	4992				
1977		16026	3745	0	20352	16379	3973				
1978		15379	4239	0	20133	15656	4477	243.4			
1979		16920	4269	0	22042	17414	4628	240.5			
1980		8475	916	0	9518	8643	875	40.7			
1981		12855	731	0	14037	13114	923	59.2			
1982		11125	470	0	11840	11313	527	54.7			
1983		12756	384	0	13467	13018	449	46.5			
1984		14160	379	0	13928	13525	403	45.2			
1985		15405	274	0	15429	15103	326	38			
1986		14558	289	0	14652	14300	352	40.5			
1987		18028	263	0	17927	17622	305	47.2			
1988		17867	224	0	19777	19540	237	58.7			
1989		19179	32	0	18939	18902	37	63.2			
1990		17350	53	0	18328	18275	53	78.3			
1991		17687	57	0	18273	18216	57	84.3			
1992		15800	29	0	17572	17543	29	83.5			
1993		15925	0	0	17659	17659	0	84.7			
1994		19467	0	0	18225	18225	0	100.4			
1995		20815	0	0	18703	18703	0	101.3			
1996		20304	0	0	19768	19768	0	87.4			
1997		21033	0	0	20407	20407	0	80.5			
1998		20765	0	0	19532	19532	0	69.9			
1999		17030	0	0	18754	18754	0	63.5			
2000		16779	0	0	16991	16991	0	42.9			
2001		15352	0	0	15112	15112	0	68.8			

Material pig iron **Thousand tonnes** **Processes**: Steel making (BOF, EAF, etc.), Iron foundries

	Beginning stock	Flux in (Import)	Produced/Extracted	Flux out(export)	Used in crude steel making	Used in Iron Foundries	recycled	disposal	End stock
1968									
1969			16653		15336	1477			622
1970	622		17672		16262	1469			484
1971	484		15416		14255	1114			656
1972	656	176.8	15316	12.1	14535	1031			496
1973	496	126.9	16838	8.2	15872	1121			450
1974	450	117.7	13903	31.7	12940	932			608
1975	608	71.0	12131	18.5	11507	862			523
1976	523	165.5	13835	60.9	12834	928			855
1977	855	150.4	12232	47.2	11753	838			704
1978	704	131.3	11434	33.8	11152	704			473
1979	473	132.7	12898	22.5	12494	709			410
1980	410	168.3	6316	30.2	6065	308			408
1981	408	110.6	9554	14.9	9473	178			94
1982	94	125.1	8389	8.0	8160	152			202
1983	202	90.9	9560	45.9	9468	182			112
1984	112	87.0	9562	33.7	9271	190			106
1985	106	101.3	10458	43.8	10125	160			157
1986	157	118.1	9785	20.0	9613	141			110
1987	110	105.4	12110	31.0	11922	139			98
1988	98	192.7	13163	22.9	13022	146			95
1989	95	64.3	12781	20.5	12771	146			85
1990	85	135.6	12463	21.1	12358	195			
1991		60.9	12062	16.4	11836	181			
1992		96.6	11679	15.7	11463	214			
1993		102.3	11579	9.9	11554				
1994		165.1	11943	2.5	11889				
1995		179.1	12236	7.9	12121				
1996		215.0	12830	4.6	12753				
1997		201.0	13055	4.4	13018				
1998		225.2	12746	1.7	12619				
1999		156.4	12139	0.4	11859				
2000		133.7	10891	0.7	10970				
2001		159.7	9870	6.7	9713				

Material crude steel **Thousand tonnes** **Process**: BOF, EAF, continuous casting, ingot casting, steel castings

	initial stock	Flux in (Import)	Produced and extracted	Produced by BOF and open hearth	Produced by EAF	Produced from continuously cast	Produced from ingot casting	Produced as alloys	Produced as non-alloys	Flux out(export)	Used for rolling mills	used for steel castings(foundries)	Recycled	Disposal	Final stock
1968															
1969			26822												
1970			28291												
1971			24153												
1972			25293	20383	4910	522	24325	1871				446.3			
1973			26594	21300	5293	811	25275	2223				507.4			
1974			22323	17065	5258	1126	20646	2090				551.2			
1975			20098	14536	5562	1704	17870	1848				523.9			
1976			22274	15518	6756	2165	19619	1991				488.8			
1977			20411	14142	6269	2554	17382	1882				474.5			
1978		247.1	20311	13111	7200	3149	16722	1895		183.1		440.6			
1979		322.9	21464	14079	7385	3627	17442	1911		165.5		395.5			
1980		306.5	11277	6698	4579	3059	7845	1236		87.4		372.8			
1981		307.5	15573	10535	5038	4958	10306	1357		84.5		308.3			
1982		263.2	13704	9036	4669	5341	8020	1205		183.3		344.5			
1983		208.7	14986	10496	4491	6986	7754	1101		443.6		246.7			
1984		266.5	15121	10295	4826	7858	7015	1231		470.8		248.5			
1985		240.3	15722	11185	4537	8620	6863	1220		736.8		238.6			
1986		231.3	14725	10560	4165	8903	5573	1138		1056.6		249.1			
1987		190.7	17414	12957	4457	11294	5896	1265		1645.9		224.6			
1988		331.0	18950	14008	4942	13356	5361	1340		1681.0		233.1			
1989		378.1	18740	13627	5113	15031	3469	1369		1470.5		239.8			
1990		324.8	17841	13169	4672	14909	2692	1200		1263.5		240.3			
1991		268.2	16474	12540	3934	14085	2201	978		1376.1		189.0			
1992		221.5	16212	12092	4120	13958	2083	1017		1199.0		170.6			
1993		230.3	16625	12330	4295	14319	2140	1067		1208.5		165.6			
1994		287.5	17286	12909	4377	15079	2033	1224		1249.5		173.9			
1995		805.5	17604	13083	4521	15250	2173	1361		1158.5		180.5			
1996		373.4	17992	13758	4233	15912	1892	1291		1193.6		188.0			
1997		463.0	18501	13988	4513	16653	1660	1306		953.7		187.0			
1998		547.5	17315	13426	3889	16346	785	1170		561.4		184.6			
1999		422.3	16284	12634	3650	15623	534	1031		416.1		127.3			
2000		526.0	15155	11551	3604	14470	539	1151		522.5		145.8			
2001		393.2	13543	10271	3272	13024	369	1046		750.6		150.2			

Material Scrap **Thousand tonnes** **Process:** crude steel making, foundries, other iron and steel making processes

	Flux in (Import)	Produced/Extracted	Flux out (export)	Used in iron & steel making	Used in producing crude steel	recycled	Disposal	Final stock
1968		19700.6		19181	15139.5			1148.1
1969		21184.9		20374	15980.7			1429.8
1970		21947.7		21274	16740.6			1508.9
1971		18949.7		18062	13949.5			1722.5
1972		18868.3		18816	14770.3			1167.2
1973		19565.4		18951	14647.4			1114
1974		18097.4		17069	12876.3			1561.4
1975		16307.7		16029	11958.5			1953.4
1976		17554.8		16973	12883.6			2520.9
1977		15427.4		15684	11858.2			2287.7
1978		15185.1		15524	11705.8			1647.7
1979		15369.3		15368	11693.8			1543.6
1980	26.5	6463.6	2807.3	9296	6357.1			858.4
1981	20.8	8093.4	3271.9	10363	7679.9			617.9
1982	37.3	7748.5	2931.1	9557	6950.5			741.5
1983	11.3	6722.2	3793.9	9635	6996.5			467.2
1984	31.7	7296	4315.5	9619	7324			439.2
1985	51.1	6993.2	4519.9	8396	6993.9			438.5
1986	47.1	6773.5	3837.2	7826	6660.2			551.8
1987	72.6	7089.4	3306.2	8203	7059.6			581.6
1988	91.4	7500.2	3609.4	8866	7699.5			382.3
1989	84.5	7988.6	3249.8	8996	7850.9			462.4
1990	60.1	7218.3	3198.4	8865	7210.1			424.9
1991	95.9	6026.5	3215.2	7526	6055.4			360.4
1992	69.4	6187.2	2796.3	7746	6305.9			365
1993	22.6	6451.9	3852.9	6522	6521.5			266.8
1994	101.5	6859	3600.1	6839	6838.5			252.6
1995	200.5	7077.9	3463.7	7000	6999.5			318.9
1996	250.1	6768.3	3430.9	6822	6822.1			259.5
1997	228.4	7183.4	3602.9	7206	7206.1			236.2
1998	179.7	6424.9	3196.9	6409	6408.5			252.6
1999	157	5921.7	3572.7	5884.2	5884.2			290.1
2000	191.9	5614.3	4384.3	5675.2	5675.2			229.2
2001	170.9	5020.5	4817.6	5025.6	5025.6			224.1

Material Steel products **Thousand tonnes** **Process:** Rolling mills, steel foundries

	initial stock	At steel producer	At stockholders	At other manufacturin	Flux in (Import)	Produced and extracted	Produced from steel foundries	Flux out(export)	Delivered to stockholders	Delivered to other industry sectors	Used in mechanical engineering	Used in electrical engineering	Used in shipbuilding	Used in vehicles	Used in str steelwork &civil eng.	Used in metal goods	Used in cans and metal boes	Used in boilers, drums and	Used in other industries	Recycled	Disposal	Final stock
1968						19488			12175	3325												
1969	7221	2821	4400		2250	20749		3665	12865	4469												8344
1970	8344	3319	5025		2237	21763		3793	12966	5037	2049	697	597	2350	1219	1303	931	389	1772			7122
1971	7122	2937	4185		2030	18761		4650	11159	3538												7725
1972	7725	3560	4165		3649	19604		4393	10637	4094	1775	641	612	2206	2342	970	1015	403	1494			8309
1973	8309	3287	5022		2773	20473		3965	12351	4949												8317
1974	8317	2485	5832		3790	17326		3031	11381	4199	1784	630	604	2090	2368	954	1013	445	1998			8145
1975	8145	2697	5448		3709	15426		2903	9667	2953	2885	794	636	2332	2568	1861	871	784	2955			9637
1976	9637	4183	5454		4079	17668		3448	9557	3481	2858	830	549	2419	2454	1910	1004	881	2620			9110
1977	9110	3981	5129		3709	15921		4176	8989	3213	2797	803	440	2438	2321	1918	1023	919	2547			8352
1978	8352	3617	4735		3664	15816		4164	8847	3483	2831	832	365	2374	2429	1964	1006	872	2459			8799
1979	8799	3842	4957		3777	17041		4326	8773	4051	2710	706	275	2111	2517	1858	1037	855	2340			7134
1980	7134	2851	4283		4611	9398		2553	5544	2680	2432	648	311	1720	2144	1662	836	646	2182			6372
1981	6372	2802	3570		3306	12640		3718	6103	3072	2049	495	308	1432	2071	1604	828	524	2110			5745
1982	5745	2545	3200		3829	11578		3281	6015	2775	2083	489	286	1553	2165	1766	808	583	1967			5520
1983	5520	2620	2900		3339	12334		3812	5752	3005	1906	440	220	1481	2066	1689	797	659	1599			5833
1984	5833	2763	3070		3544	12706		3843	5849	3187	1803	509	183	1399	2049	1825	829	641	1805			6123
1985	6123	3233	2890		3749	13543		4562	5796	3121	2079	626	192	1616	1998	1752	806	645	1791			5357
1986	5357	2777	2580		4133	12685		4930	5502	2835	2144	604	122	1592	2300	1798	793	681	1670			5579
1987	5579	2899	2680		4284	15133		6065	5890	3306	2237	639	105	1734	2717	1809	829	653	1513			5654
1988	5654	2944	2710		4536	16727	343.7	4584.2	6693	4087	2595	652	89	1988	3562	1943	913	584	1706			5804
1989	5804	2874	2930		4776	16810	354.2	4873.7	6653	4254	2749	721	45	1843	3732	2029	782	608	1957			5449
1990	5449	2809	2640		4721	16016	356.1	5455.5	6095	3616	2530	695	73	1705	3238	1015	703	452	3433			4994
1991	4994	2754	2240		4932	14978	281	6151.5	4929	3022	2011	579	74	1397	2875	733	794	224	3022			4776
1992	4776	2506	2270		4830	14654	264.9	6699.5	4384	2931	2080	600	79	1557	2557	766	772	283	2790			4790
1993	4790	2430	2360		4319	15027	258.8	6508.3	4356	3211	1705	623	60	1961	2827	738	726	290	3038			2335
1994	2335	2335			5409	15605		6989	4452	3375	1936	658	65	2065	3156	808	702	319	3192			2341
1995	2341	2341			5466	16091		7049.6	4546	3711	2391	662	70	2131	3161	768	664	299	3221			2281
1996	2281	2281			5486	16628		7298.8	4475	3908	2064	673	70	2268	3255	751	604	269	3100			2304
1997	2304	2304			5732	17183		7706.5	4386	4240	2262	728	47	2340	3434	999	564	307	3057			2212
1998	2212	2212			6393	16044		7406.5	4231	4029	2602	696	74	2389	3117	1125	645	316	3165			2066
1999	2066	2066			6695	14923		7543.7	3932	3721	2107	631	44	2306	3217	1042	629	284	2823			1794
2000	1794	1794			7124	14146		7313.1			2181	771	20	2420	3139	917	578	258	2863			2387
2001	2387	2387			7697	13537		6089														5754.3

Appendix 4.1 EAA aluminium end user sectors classification

A.	**TRANSPORT**
A.1	**Road transport**
A.1.1	Motor cars and estate cars
A.1.2	Commercial, insdustrial and public transport vehicles including tractors, semi-trailers and special road vehicles
A.1.3	Cycles, motor cycles, mopeds, invalid chairs, perambulators, etc.
A.1.4	Parts common to sub-headings, A.1.1 to A.1.3 and to main heading A.2, or not reportable separately
A.2	**Caravans and mobile homes**
A.3	**Shipbuilding**
A.3.1	Merchant marine, naval and fishing vessels
A.3.2	Pleasure boats and small craft, including outboard motors
A.3.3	Special craft (Hovercraft, hydrofoils, etc.)
A.3.4	Parts common to sub-headings A.3.1 to A.3.3, or not reportable separately Excluding outboard motors-reportable under sub-heading A.3.2
A.4	**Rail transport**
A.4.1	Locomotive units
A.4.2	Passenger carriages, including underground railway units, tramcars and rail-cars
A.4.3	Freight cars including tankers, refrigerated cars, etc.
A.4.4	Special rail vehicles, and parts common to sub-headings A.4.1 to A.4.3, not reportable separately
A.5	**Aircraft and areospace construction**
A.6	**Funiculars, cog railways, ski-lifts and the like**
A.7	Containers, air, land, sea
A.8	**Combustion engines,** other than reportable under main headings A.1 to A.5
B.	**GENERAL ENGINEERING**
B.1	**Industrial machinery and accessories**
B.1.1	Textile, dyeing, hosiery, knitting, laundry and leather
B.1.2	Paper making, printing and packaging equipment
B.1.3	Plastics and rubber
B.1.4	Heating processes, ventilation, drying, boilers, heat exchangers, air cleaning and generation, thermal insulation
B.1.5	Other than reportable under sub-headings B.1.1 to B.1.4, but including all foil for general engineering use*) (see note on page 27)
B.2	**Industrial cocks, taps, pumps and couplings**
B.3	**Machine tools, welding equipment, portable power and hand tools**
B.3.1	Machine tools and accessories
B.3.2	Welding equipment and accessories, including electrodes
B.3.3	Portable power and hand tools Excluding gardening hand-tools reportable under sub-heading E.4.1
B.4	**Lifting, transfer and handling equipment**
B.4.1	Equipment, incorporating or alternatively being part of lifting or transfer machinery
B.4.2	Other equipment
B.4.2.1	Food
B.4.2.2	Non-food

B.4.2.3	Common to sub-headings B.4.2.1 and B.4.2.2 or not reportable separately
B.5	**Precision engineering, medical apparatus, instruments**
B.5.1	Clocks and watches, and dials of all types
B.5.2	Optical, photographic, cinematographic
B.5.3	Measuring and control instruments
B.5.4	Medical apparatus and instruments
B.5.5	Parts common to sub-headings B.5.1 to B.5.4, or not reportable separately
B.6	**Mining, open-cast mining, and earth-moving equipment**
B.7	**Nuts, bolts, nails, building fixings, mechanical couplings**
B.8	**Bars for machining, if not separately identifiable by ende-use**
C.	**ELECTRICAL ENGINEERING** Excluding domestic electric appliances, radio and T.V. sets, electrical office machinery-reportable under Basic heading G
C.1	**Power transmission and distribution**
C.1.1	Bare (non-insulated) overhead conductors (cables) wire for:
C.1.1.1	All-aluminium conductors (cables)
C.1.1.2	Steel-cored aluminium conductors (cables) (net weight of aluminium)
C.1.2	Insulated and protected cable and wire excluding telephone, ect. cable
C.1.3	Flexible woven cables, bare and insulated
C.1.4	Wire non-insulated electrical, not otherwise recorded
C.1.5	Busbars (bars, tubes sections, etc.) and enclosures
C.1.6	Pylons, towers and structures
C.1.7	Line and cable-laying accessories
C.2	**Electrical machinery**
C.2.1	Rotating electrical machines Excluding windings-reportable under sub-heading C.2.3
C.2.2	Static electrical machines Excluding windings-reportable under sub-heading C.2.3
C.2.3	Windings, wire and strip
C.2.4	Other electrical machinery and parts thereof, common to sub-headings C. 2.1 and C.2.2, not reportable separately
C.3	**Telephones, communications and electronics** Excluding radio, television sets, recorders and part thereof-reportable under Main heading G.3
C.3.1	Telephones, communications and electronics equipment
C.3.2	Wire of telephones, communications and electronics
C.4	**Domestic/industrial equipment**
C.4.1	Lamb bulbs caps, switches, plugs, conduits, etc.
C.4.2	Industrial electrical equipment, other than reportable under main headings C.1 to C.3, but including all foil for electrical use*) (See note on page 27)
C.5	**Atomic energy (nuclear reactors)**
D.	**BUILDING, CONSTRUCTION AND PUBLIC WORKS**
D.1	Building and construction: structures, including scaffolding-Excluding

	structures reportable under sub-heading C.1.6 or under main heading D.6 (Public Works)
D.2	**Building and construction: roofing, exterior cladding and accessories**
D.2.1	Corrugated material and accessories-excluding fixings, bolts, etc. reportable under main heading B.7
D.2.2	Other-Excluding fixings, bolts, etc. reportable under main heading B.7
D.3	**Building and construction: doors, windows, curtain-walling, etc.**
D.3.1	Window and door frames, doors (including folding) curtain-walling, panels and partitions
D.3.2	Shop fronts Excluding internal fittings-reportable under sub-heading D.5.7
D.3.3	Shutters (solid), sun-shades, blinds (including venetian)
D.4	**Building and construction: prefabricated houses and buildings, including glasshouses**
D.5	**Building and construction: general equipment, including decoration**
D.5.1	Heating, air conditioning and ventilation equipment, in buildings
D.5.2	Balconies, balustrading, railings, shutters (open-work) and gates
D.5.3	Acoustic and other ceilings (including heated)
D.5.4	Swimming pools and equipment
D.5.5	Garage and industrial doors
D.5.6	Hardware (doors, windows, etc.)
D.5.7	Other than reportable under sub-headings D.5.1 to D.5.6, but including all foil for building use*) (See note on page 27)
D.6	**Public works** Excluding buildings
D.6.1	Airport and harbour general equipment, and railway track equipment Excluding the electrical equipment
D.6.2	Motorway, road and street equipment
D.6.3	Public works equipment other than reportable separately under sub-headings D.6.1 and D.6.2
E	**INDUSTRIAL REFRIGERATION, ETC., CHEMICAL, FOOD AND AGRICULTURAL PLANT AND EQUIPMENT**
E.1	**Industrial ice production, deep freezing and refrigeration**
E.2	**Chemical industry**
E.2.1	Nuclear chemistry
E.2.2	Oil (petroleum), gas industry and cryogeny
E.2.3	Other chemical industries
E.3	**Food and drink industries** Excluding beer barrels-reportable under subheading F.4.1
E.3.1	Brewery and Dairy plant and equipment
E.3.1.1	Brewery
E.3.1.2	Dairy
E.3.2	Other food industries, and equipment common to main heading E.3 not reportable separately
E.4	**Agriculture**
E.4.1	Farming and forestry
E.4.2	Irrigation
F	**PACKAGING**

F.1	**Impact extrusions for packaging uses**
F.1.1	Collapsible tubes
F.1.2	Other impact extrusions
F.1.2.1	Rigid tubes
F.1.2.2	Aerosols
F.1.2.3	Cans
F.2	**Cans (other than impact extrusions), can-ends and lids**
F.2.1	Aerosol cans
F.2.2	Other cans, cand-ends and lids
F.3	**Jar and bottle closures and caps (thickness over 0,2 mm)**
F.4	**Barrels, Flasks and Drums**
F.4.1	Beer barrels
F.4.2	Other
F.5	**Other packaging, not reportable under F.1 to F.4 and F.6**
	Excluiding baskets, bins, pallets-reportable under sub-heading B.4.2
F.6	**Foil for packaging (thickness not exceeding 0,2 mm) net weight of aluminium*)**
	(See note on page 27)
G.	**DOMESTIC AND OFFICE EQUIPMENT**
G.1	**Holloware and kitchen utensils including camping**
G.1.1	Holloware, including mugs and plates
G.1.2	Kitchen untensils and accessories, including forks, spoons, etc.
G.2	**Domestic machines and appliances including camping**
G.2.1	Electrical
G.2.2	Non-electrical
G.3	**Radio and Television sets, record players, etc., and accessories**
G.4	**Light fittings and equipment**
G.5	**Office and School equipment**
	Excluding furniture-reportable under main heading G.6
G.5.1	Office machines
G.5.2	Office and School accessories
G.6	**Furniture, including office, camping and garden**
G.7	**Other domestic appliances and accessories**
H.	**POWDER AND PASTE**
H.1	Lamellar powder and flakes
H.1.1	Paint, ink and maintenance products
H.1.2	Other uses
H.2	**Non-lamellar powder**
	Excluding that for steel de-oxidation and metal for alloy production reportable under Basic heading I
H.2.1	Alumiothermic charges
	Excluding metallurgical applications-reportable under Basic heading I
H.2.2	Other uses
H.3	**Paste (aluminium content assumed as average 67 % net weight)**
I.	**IRON, STEEL AND OTHER METALLURGICAL USES**
I.1	**Steel de-oxidation**
I.2	**Ferro-alloy production, including aluminothermic process**
I.3	**Other alloying and metallurgical uses**
J.	**MISCELLANEOUS**
J.1	**Metalwares**

J.1.1	Fancy goods, including costume jewellery
J.1.2	Haberdashery
J.1.3	Games, travelling, music and sports Excluding fire-arms-reportable under main heading J.2
J.1.4	Plates and signs Excluding licence plates-reportable under sub-headings A.1.4 and traffic signs reportable under sub-heading D.6.2
J.1.5	Ladders, step-ladders, trestles, etc.
J.1.6	Other metalwares Excluding those reportable under sub-headings J.1.1 to J.1.5
J.2	**Arms and Ammunition, including sporting, and miscellaneous Defense equipmet**
J.3	**Despatches to stockists, if not separately identifiable by ende-use**
J.4	**Miscellaneous uses not specified under headings A to J.3, including materials destined for further fabrication outside the Aluminium Industry**
J.4.1	Destined for further fabrication outside the Aluminium Industry and not recordable later
J.4.2	Other, including foil, for converters, and that not otherwise identifiable

Z.	**EXPORTS** Total National recorded Exports (i.e. Classifications 76-02 to 76-06 inclusive, 76-12 and ex 32-09) of which Reported **direct** exports of the Aluminium Industry were...

Appendix 4.2 Trade classifications of goods containing aluminium

Trade statistics are given according to SITC (Standard Industry Trade Classifications) codes. These classifications have been revised three times since 1968, only the latest classification codes (SITC Rev.3) are shown here. In the material flow analysis, the classifications valid for the particular year data have been collected have been used. Data on product groups that contain aluminium have been collected; the product groups are given in table 1 grouped into the six categories applied in the material flow analysis.

Source: Overseas Trade Statistics - UK Trade with the EC and the World 1998, HM Customs and Excise, UK Tariff and Statistical Office.

SITC code	
	Transport
781	motor cars and other m/vehicles principally for transport of persons (O/T public transport v.)
782	motor vehicles for the transport of goods and spec. purposes vehicles
783	road motor vehicles, NES
784	parts and accessories of motor vehicles
785	motor cycles (incl. mopeds) and cycles, motorised and non-motorised
786	trailers and semi-trailers; other vehicles not mech. propelled
79	other transport equipment (incl. railway vehicles, aircraft, ships etc)
	Building/Construction
691.2	aluminium structures (O/T pre.fab buildings) & parts thereof; plates rods etc, PRD for use in structures
694.4	nails, tacks, staples, screws, bolts, nuts, screw hooks, rivets & similar articles of aluminium
	Engineering
711	steam or other generating boilers, super-heated water boilers, & aux plant for use therewith
712	steam turbines and other vapour turbines, and parts thereof, NES
713	internal combustion piston engines, and parts thereof, NES
714	engines and motors (O/T those of 712, 713 & 718); parts, NES, of these engines and motors
716	rotating electric plant and parts thereof, NES
718	other power generating machinery and parts thereof
724	textile and leather machinery, and parts thereof, NES
725	paper mill and pulp mill machinery
726	printing and bookbinding machinery
728	other machinery, NES
73	metalworking machinery
74	general industry machinery and equipment, NES
76	telecommunications and sound recording and reproducing apparatus and equipment
77	electrical machinery, apparatus and appliances, NES and electrical parts thereof
721	agricultural machinery (excl. tractors) and parts thereof

727	food-processing machines (excl. domestic)
	Packaging
	(Not reported)
	Consumer durables
75	office machines and automatic data processing machines
697.43	household articles and parts thereof, NES, of aluminium
699.79	articles of aluminium, NES
821.3	furniture, NES, of metal
697.53	sanitary ware and parts thereof, NES, of aluminium
697.8	household appliances, decorative articles, frames and mirrors, of base metal, NES
693.13	stranded wire, ropes, cables, plaited bands, slings and the like, of aluminium, not electrically insulated
699.1	locksmiths' wares, safes, strong boxes, etc and hardware, NES, of base metal
699.5	miscellaneous articles of base metal; eg bells, signs, electrodes etc.
	Other
692.44	containers of aluminium for compressed or liquefied gas
692.12	reservoirs, tanks, vats and similar containers, of aluminium, >300 litres
692.42	tanks, casks, drums, cans, boxes & similar CTR of aluminium, < 300 litres, O/T for compressed or liquefied gas

Appendix 4.3 Aluminium time series data

Material Bauxite Tonnes Process: Bayer

	Beginning stock	Flux in (Import)	Produced/Extracted	Flux out (export)	Used in bayer process	recycled	Disposal	Final stock
1958		356563		193				
1959		332858		420				
1960		381418		79				
1961		401354		1				
1962		432704		206				
1963		336510		0				
1964		379544		67				
1965		444969		2				
1966		491594		5				
1967		457985		0				
1968		442173		0				
1969		478385		0				
1970		413326		206				
1971		447186		142				
1972		318691		42				
1973		298801		519				
1974		323987		248				
1975		295781		396				
1976		296537		97				
1977		345814		463				
1978		321381		466				
1979		283988		1409				
1980		267633		11105				
1981		240688		883				
1982		310130		749				
1983		256068		716				
1984		316908		848				
1985		257531		1412				
1986		270766		576				
1987		33095		1042				
1988		40562		914				
1989		31937		5370				
1990		53730		1387				
1991		289623		2122				
1992		312468		1333				
1993		250680		934				
1994		249336		0				
1995		291492		0				
1996		205490		0				
1997		3294		0				

1998		648		0				
1999		13519		0				
2000		5077						
2001		163363						
2002								

Material Alumina **Tonnes** **Process**: Electrolysis

	Beginning stock	Flux in (Import)	Produced/Extracted	Flux out (export)	Used in electrolysis	recycled	Disposal	Final stock
1958		243		38857				
1959		6179		33961				
1960		7169		26780				
1961		4750		24211				
1962		9992		16079				
1963		4962		19770				
1964		8743		17415				
1965		9766		21272				
1966		6971		13879				
1967		6051	135300	22198				
1968		5894	117400	17123				
1969		8686	105700	10152				
1970		54266	107100	3402				
1971		272126	99100	18739				
1972		305962	116100	19333				
1973		534203	96900	33328				
1974		602030	94700	110572				
1975		563892	82500	24669				
1976		525753	96000	43024				
1977		702853	98500	43360				
1978		699455	94000	36062				
1979		609838	88000	33105				
1980		778908	102000	42670				
1981		630421	90000	39622				
1982		457034	88000	37018				
1983		488882	93000	37928				
1984		661954	105000	43975				
1985		572793	110000	45121				
1986		546329	110000	46733				
1987		629178	110000	49492				
1988		639637	114000	49149				
1989		404666	116000	54906				
1990		625285	120000	53841				
1991		609581	120000	53706				

1992		561978	120000	48683				
1993		356839	120000	39352				
1994		520036	110000	16238				
1995		578811	108000	21861				
1996		666345	99000	22673				
1997		648312	100000	16887				
1998		504526	96000	19233				
1999		600725	115000					
2000		648645						
2001		703979						

Material Unwrought Aluminium **Tonnes** **Process**: semi-fabrication &foundries

	Initial stock	Flux in (Import)	Produced/extracted	From primary	From secondary	Flux out (export)	Used in semi-fab/foundries	From primary	From secondary	Imports (Alfed) 1000 t	Exports (Alfed) 1000 t	recycled	Disposal	Final stock
1958		213761	127400	26800	100600	2229	334600	235300	99300					
1959		254288	133900	24900	109000	3851	401600	291800	109800					
1960		316289	136300	24900	111400	4759	464100	357200	106900					
1961		239743	151800	32800	119000	5567	395500	282600	112900					
1962		255238	166400	34600	131800	5469	412300	285400	126900					
1963		271140	180100	31100	149000	7564	459400	317500	141900					
1964		331068	203800	32200	171600	7325	524400	356200	168200					
1965		321825	214200	36200	178000	24499	517200	350600	166600					
1966		346267	220700	37100	183600	26434	524300	362900	161400					
1967		307429	217600	39000	178600	22224	516500	356600	159900					
1968		361837	226200	38200	188000	21319	562600	388400	174200					
1969		357672	243300	33800	209500	22243	581100	387700	193400					
1970		379140	241000	39600	201400	26084	583400	404200	179200					
1971		269681	300600	119000	181600	43195	488800	325600	163200					
1972		266867	356200	171400	184800	84962	577000	408200	168800					
1973		287080	440900	251600	189300	85328	664400	487800	176600					
1974		280753	482000	293100	188900	87285	654500	493600	160900					
1975		160279	484500	308300	176200	87695	533900	392700	141200					
1976		217901	540300	334500	205800	162085	585200	444500	140700					
1977		202161	550500	349700	200800	145795	557900	418100	139800					
1978		190855	539800	346200	193600	160515	538300	402300	136000					
1979		182147	536000	359400	176600	206984	533500	417600	115900					
1980		171420	536400	374400	162000	194456	490900	409300	81600					
1981		123347	487000	339100	147900	171179	433500	343600	89900	168.3	123.2			
1982		154180	355300	240800	114500	119518	400900	326300	74600	119.4	154.8			
1983		163637	380600	252500	128100	132412	412700	323400	89300	128.4	162.3			
1984		172144	431600	287800	143800	127560	467200	369500	97700	121.7	170.1			
1985		147350	402800	275300	127500	129114	431500	350400	81100	122.9	146.1			
1986		182166	392100	275800	116300	116756	460200	389100	71100	112.5	180.4			
1987		175823	411000	294300	116700	133555	463900	383600	80300	127.7	175.0			
1988		235014	500200	300200	200000	155050	587400	427400	160000	150.0	240.5			
1989		235451	517300	297300	220000	169195	624700	454700	170000	163.7	232.4			
1990		241029	491200	289800	201400	156600	589800	453700	136100	151.2	237.2			
1991		196912	488600	293500	195100	130321	534600	412400	122200	124.4	194.8			
1992		367869	441500	244200	197300	135160	711800	550000	161800	129.8	342.7			
1993		589100	475200	239000	236200	128942	714700	540000	174700	127.8	587.3			
1994		477013	455500	231200	224300	220137	790000	570000	220000	220.0	476.6			
1995		388090	467600	237900	229700	313854	752100	620000	132100	305.2	386.8			
1996		651368	500000	240000	260000	205283	688900	571000	117900	205.3	418.3			
1997		436895	490400	247700	242700	372862	713600	583000	130600	372.9	436.8			
1998		495089	533200	258400	274800	225234	723600	579000	144600	225.3	495.1			
1999		444044	555000	269700	285300	233191	732600	581000	151600	376.7	461.8			
2000		277147	542800	305100	237700	347704	756105	575520	180585	431.9	300.5			
2001		346892	589400	340800	248600	263342	655626	433302	222324	263.3	346.9			

		Flux in (Import)	Produced/extracted	Flux out (export)	Used by refiners	Used by semi manufacturers	Used by refiners and semi manufacturers (Alfed), t	recycled	Disposal	Final stock
1958		1620		56	117660.8	14700				
1959		6805		136	127485.4	15000				
1960		15947		96	130292.4	17200				
1961		5804		2844	139181.3	11700				
1962		8572		4300	154152	9200				
1963		9136		2342	174269	10000				
1964		12203		1589	200701.8	10500				
1965		23856		6899	208187.1	11500				
1966		16237		7609	214736.8	15900				
1967		14132		2036	208888.9	14300				
1968		12985		1617	219883	16100				
1969		13142		1315	245029.2	15100				
1970		15471		1886	235555.6	19500				
1971		11888		2084	212397.7	24500				
1972		13928		2994	215501	31000				
1973		20697		3455	225734	23200				
1974		22220		13033	224230	26700				
1975		13670		16720	199218	31300				
1976		17250		7021	240701.8	32500				
1977		6207		9742	234853.8	31100				
1978		10807		13288	209032	29300				
1979		9902		30536	188315	26900				
1980		7858		36058	177446	28500				
1981		4038		38008	157939	30600				
1982		3534		49080	126783.6	31500				
1983		10271		67346	143391.8	33100				
1984		6236		76445	160233.9	30100				
1985		4409		80284	142456.1	28800				
1986		7275		77646	128771.9	31700				
1987		11638		75971	129590.6	33100	162690.6			
1988		18606		114287	233918.1	35000	490981.3			
1989		24138		99334	257309.9	35000	499513.9			
1990		16865		94452	235555.6	35000	485871.6			
1991		29044		80172	228187.1	35000	464863.8			
1992		40332		71974	230760.2	35000	519693.6			
1993		44745		90801	276257.3	35000	621325.6			
1994		59907		100723	262339.2	35000	692115.2			
1995		74580		105461	268655	35000	720551.3			
1996		84138		100021	300818.7	35000	740789.6			
1997		109300		107359	285964.9	35000	747958.2			
1998		133407		117501	321403.5	35000	804098.1			
1999		132533		102121	333684.2	35000	826915.9			
2000		133801		143380	282222.2		746855.1			
2001		110076		208289	290760.2		774757.8			

Material Semis and casting **Tonnes** **Data Source** WBMS

	initial stock	Flux in (Import)	Produced and extracted	Flux out(export)	Delivered to transport	delivered to mechanical eng	Delivered to electrical eng	Delivered to construction	Delivered to chemical, food, etc.	Delivered to packaging	Delivered to domestic&office	Delivered to powder consuming	Delivered to steel industry	Delivered to metal industries nes +misc	Delivered to miscellaneous	Recycled	Disposal	Final stock
1958		3561	317857	39677	87484	19393	26084	20398	3787	25179	32063	3888	13571	35023	24951			
1959		6621	366660	85029	98943	21780	31950	23014	4441	27809	40057	5554	13720	41542	30741			
1960		14058	409975	54467	111374	26652	35374	31526	5503	29235	37006	6087	16937	51836	37051			
1961		22023	378609	58094	94468	23038	33774	31569	5520	26257	33563	5251	13083	45645	33649			
1962		23300	384963	63833	96647	23567	34481	27808	5596	24389	36734	5193	12964	45663	34086			
1963		26454	416261	67824	112558	23622	43132	29222	7526	27232	42563	4968	12377	46313	36555			
1964		29245	451436	55530	125805	27371	51697	35119	7986	27353	42412	5931	14649	55220	46148			
1965		26096	466201	61689	121047	26559	59289	36692	9072	29537	41455	6918	15224	56935	47932			
1966		31238	476010	58770	123253	27281	59668	35061	8033	31145	39334	7860	15630	55668	48162			
1967		31055	476004	47518	124414	25401	62648	34476	8703	30931	39994	6145	14010	55057	46947			
1968		39663	476004	49582	135340	27431	64220	36353	10382	36732	47675	7622	15873	57862	49802			
1969		48391	509805	50278	147398	30731	60489	36680	12425	36237	45396	8005	19684	65487	57555			8344
1970		80378	531435	54770	134000	28300	64600	36000	15300	35100	43400	10300	21700	66300	58800			7122
1971		81431	434400	42300	127809	23946	56006	34416	13122	33954	39947	7222	21530	60623	52555			7725
1972		89515	469700	63515	131825	24994	56012	42238	10841	38290	44864	8374	23283	72308	63085			8309
1973		96344	545100	96644	158190	36467	65378	54907	7218	47719	55504	7448	21397	70205	54421			8317
1974		133720	563400	63573	143682	41588	78158	61979	7589	53991	49020	10874	21623	71627	n/a			8145
1975		79968	473000	71237	117200	31300	66100	51500	5700	43100	44800	7600	18400	52900	n/a			9637
1976		128979	473000	80566	123700	34900	63100	59800	3700	45300	50600	9200	23100	71400	n/a			9110
1977		145713	473000	85474	115000	30900	54600	55600	3900	50500	47000	12300	20800	80900	n/a			8352
1978		165349	507083	68020	103600	23800	53100	59100	3400	49100	42400	7000	19500	92600				8799
1979		189425	536311	81955	103900	23900	52900	70200	1800	44100	37700	9400	18900	136600				7134
1980		155964	487600	114855	72500	21400	49300	63000	1700	44200	28900	7400	19200	103300				6372
1981		169807	411700	87744	62500	17300	43400	62600	1300	39700	24000	6100	19400	83200				5745
1982		210166	422600	104566	56900	20100	40500	67900	1400	41600	23500	5600	20400	83800				5520
1983		237981	430900	103604	55600	21300	36800	77900	1100	45100	22900	6900	18800	60700				5833
1984		248593	444250	115206	51100	26300	41000	76400	1000	55300	19200		23000	81000				6123
1985		237730	437104	115342	52400	28900	40800	70000	1500	55800	17900		21700	81100				5357
1986		252016	465054	134390	52700	33300	33500	77100	1100	58900	21900		19600	83200				5579
1987		300323	491818	144702	55700	33100	38400	84000	1100	56700	23600		16600	90300				5654
1988		310703	458373	137705	64100	32600	39300	87200	700	52500	26400		16000	86200				5804
1989		340701	425241	157370	18400	19600	8300	72600	300	88000	15200			77900				5449
1990		352301	437485	172780	13700	15700	4500	62100	300	88000	15200			73700				4994

1991		292198	419711	213147	22800	34800	28000	64100	300	88000	15200			20400				4776
1992		384980	598800	209886	17100	27100	24600	54500	400	95100	13200			66900				4790
1993		316235	592557	237799	17000	26600	19500	49200	0	96100	14800			59800				2335
1994		365779	642873	263664	106400	39300	24000	75500	500	120500	20300			72900				2341
1995		374160	649873	295849	109800	39000	23900	75300	5300	104700	18200			81900				2281
1996		381849	594674	266074	94500	36500	17700	66300	500	106700	15700			75600				2304
1997		377727	754434	276266	19800	37300	3500	72200	400	107100	2100			77000				2212
1998		384655	633966	299261														
1999		370855	268600	303966														
2000		487526	738700	347385														
2001		490919	690500	331930														

Material: semis and casting **Thousand tonnes** **Data source**: Alfed

	initial stock	Flux in (Import)	Produced and extracted	Flux out(export)	Delivered to transport	delivered to engineering	Delivered to building and construction	Delivered to packaging	Delivered to consumer durables	Delivered to others	Recycled	Disposal	Final stock
1978			508.8		138.78	61.68	126.12	77.654	7.58	33.07			
1979			535.0		133.58	64.79	138.98	85.854	8.38	35.99			
1980			478.2		117.38	58.75	126.33	81.754	7.98	31.98			
1981		140.3	410.7	59.3	106.45	59.37	129.44	94.218	9.19	30.65			
1982		176.0	422.2	79.6	106.53	62.82	139.73	102.623	10.01	32.75			
1983		194.4	430.1	73.9	109.89	67.35	152.66	110.618	10.79	35.91			
1984		202.2	444.5	89.6	110.68	67.95	151.97	115.005	11.22	34.92			
1985		192.7	436.1	85.5	106.00	66.17	148.85	112.75	11.00	34.14			
1986		207.8	463.2	103.8	109.49	69.50	155.64	121.688	11.87	35.00			
1987		244.9	528.0	103.8	146.07	83.04	179.82	137.022	13.37	41.47			
1988		232.9	545.1	107.3	153.52	84.37	182.57	133.373	13.01	43.22			
1989		242.3	545.4	123.4	151.60	82.97	177.49	133.619	13.04	41.38			
1990		267.4	548.8	142.8	146.70	84.24	174.90	152.397	14.87	37.09			
1991		265.5	518.0	177.3	129.25	74.77	150.77	143.336	13.98	29.94			
1992		288.7	598.2	233.5	146.89	81.12	159.29	154.324	15.06	31.35			
1993		251.5	592.0	190.0	158.19	82.13	156.13	153.094	14.94	30.70			
1994		318.0	643.1	218.6	175.17	93.58	176.83	182.081	17.76	33.17			
1995		338.8	648.3	251.4	177.90	94.12	177.26	181.999	17.76	33.39			
1996		328.6	633.5	201.3	186.70	97.59	185.87	182.86	17.84	36.41			
1997		319.9	663.6	214.5	185.45	98.65	190.43	184.746	18.02	37.64			
1998		307.4	668.5	219.8	181.30	97.10	189.98	179.375	17.50	38.33			
1999		366.1	668.7	214.1	182.23	105.31	215.72	196.472	19.17	44.29			
2000		477.0	738.7	323.9	188.97	114.25	237.90	217.382	21.21	48.47			
2001		404.8	690.9	218.9	183.59	112.38	236.45	212.708	20.75	48.67			