Recycling
taking aluminium as an example
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Historical aspects

It could be said that over the past 30 years, the word "recycling" has become something of a household word. There is a positive aura about it and the use of it is a sure way of assuring social acceptance for oneself. This acceptance of the word is founded on such a widely spread public opinion, at least in the industrialized world, that one could be forgiven for thinking we had invented recycling.

Far be it. The reuse of materials with properties that are necessary or for which there is a demand, has prevailed since the beginning of time. The materials our ancestors had at their finger tips have even lent their names to the respective eras; the stone age, the bronze age, the ice age.

For our stone age ancestors, for example, it was perfectly natural to maintain the raw materials sought and often found by coincidence, such as meteor-iron, for as long as possible. Contrary to the worn out obsidian chisel, a scraper out of meteor iron could be hammered with firestone and maintained for as long as one liked.

Some thousands of years later, it was discovered how metals could be produced out of ore with the help of wood or charcoal. The production process was difficult and in those days there were only a few experts who knew how to do it; consequently the metals were rare and because of their exceptional and manifold characteristics, were always in high demand and of course expensive.

Our ancestors were just as innovative and clever as we are. Obviously they reused the products made from the highly coveted and expensive metals, once these products had forfeited their usability during the course of time. Yet they did not melt everything down – as I have just said, this was extremely difficult at the time – but they simply reforged them. A new conqueror, for example, generally had the gold coins from his predecessor simply remoulded – this was nothing but a form of recycling. Any moderately sized settlement always boasted a blacksmith, whose task it was to restore used utensils by reforging them so that they could be used again. European family names reflect the traces of this “recycling sector” in endless varieties – Smith, Smid, Schmied or Smitts.

So it seems legitimate to me to ask what have we been able to add to the ancient skills of recycling?
Recycling defined as a system

Because the methods have been developed further, we now have sound theoretical knowledge and many sophisticated techniques at our disposal, so we can apply our recycling processes very much more efficiently than our ancestors were able to do.

What is really new, however, is our own understanding of recycling. We see it as a complex system of interlinked material flows that in the course of time are re-directed back into circulation again. Before going into detail, it makes sense to define what we mean by a “system”. I’ve worked my way through a number of well-known reference books and find that a “system is a collective entity made up of basic insights; it is a principle upon which something is organized or assembled”. This definition has always been of help to me while struggling through the labyrinth of prevailing definitions of the word “recycling”. Today, recycling, as system, is determined by parameters which are not found in classical metallurgy, i.e. in the discipline of the production of metals from their ores. These parameters can be trends in fashion, they can be amendments to legislation or prevailing ideologies. Such criteria have a tremendous impact on the form, the composition and the function of a product, such as a car. Today a good 100 kg aluminium goes into the production of a vehicle and the trend is on a sustained up.

There are two ideas in this last sentence that are of paramount importance: aluminium and sustainability. I will be taking a closer look at them both, but for the moment, let me go back to the car. The materials used and the nature of their compounds in the car demonstrate the subjective criteria of influence I have just mentioned, namely the prevailing appreciation of fashion, the official recommendation to save on fuel, the need for safety and comfort, to mention but a few. At the end of a life cycle of a car, it is these factors, the selection of materials and their joining up in a vehicle which will determine the car’s recyclability. Please forgive this over-simplification but in fact, factors such as these decide how effectively a car can be changed back into raw materials, these raw materials used again to produce another car... and so on.

This actuation of the cycle from the raw material to the product and at a later period of time from the product back into the raw material and the sustaining of this actuation is what we understand today by “recycling”.

Contemporary definition of recycling

The public notion of recycling is unfortunately rendered even more complex by the fact that not only does one speak of metal recycling or vehicle recycling, but also of glass, paper and plastic recycling.

People trained in metallurgy, such as myself, know that metals are first of all elements and as such they are monatomic. In the periodic system of elements common to the natural sciences, the primary recycling materials, namely metals, together with all the cosmic elements we know, are marked in blue; the metals marked in green are synthesized by the nuclear scientists and the rest are the so-called non-metals.

By the very nature of the definition of chemical elements, the recycling of an aluminium atom, even if carried out a thousand times in theory, would lose nothing of its fundamental characteristics; an aluminium atom stays an aluminium atom.

By contrast, the recycling of a complicated organic molecule would come up against major difficulties. Even solar radiation will in time destroy single chemical bonds of an intricately constricted plastic molecule; during usage and in the course of the various different thermal recycling stages, other inner-molecular bonds are automatically split open or repositioned. Any change in a chemical bond in a large molecule, however, always leads to a change of properties and generally to a loss of desirable characteristics. This is why it will never be possible to reuse polyethylene foils that have been used all summer in place of glass as roofing for a greenhouse of tomatoes and make identical, transparent polyethylene foils out of them again. Recycling into anything like the same quality is only possible after mixing large quantities of fresh polyethylene to make up for the degradation of characteristics.

In place of these somewhat contradictory definitions that are hard to appreciate, let me give a simple definition of recycling:

“Recycling means: Treatment or processing of residual materials or goods — whether scrapped or rejected during fabrication or after their life span — to recover its content of valuable components for reuse in industrial cycles.”

The difference between the extreme examples of the recycling of aluminium and the recycling of plastics lies in the degree of quality that can be achieved by recycling without virgin material being added. The aluminium from the cylinder block of a car will give another cylinder block with only a minimum of metal being added for
purposes of analysis correction, whereas the plastic from food package foils will only ever produce a garbage bag.

Aluminium

I am now going to restrict myself to the metal aluminium — and this, for good reason. After steel, it is by far the most important metal in the world. The table makes this quite clear.

### Consumption of Metals in the year 2000

<table>
<thead>
<tr>
<th>Metal</th>
<th>Europe</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>160,0</td>
<td>771,0</td>
</tr>
<tr>
<td>Aluminium</td>
<td>6,60</td>
<td>24,90</td>
</tr>
<tr>
<td>Copper</td>
<td>4,43</td>
<td>15,10</td>
</tr>
<tr>
<td>Zinc</td>
<td>2,53</td>
<td>8,58</td>
</tr>
<tr>
<td>Lead</td>
<td>1,84</td>
<td>6,15</td>
</tr>
<tr>
<td>Nickel</td>
<td>0,41</td>
<td>1,14</td>
</tr>
<tr>
<td>Tin</td>
<td>0,06</td>
<td>0,265</td>
</tr>
</tbody>
</table>

*Fig 2: Consumption of base metals*

Not only this, aluminium is by far the most common metallic element found in the 30 kilometre depth of the earth’s crust, accounting in fact for about 8%.

The light metal aluminium, that has a density of 2.7 t/m³ is about 2/3 lighter than steel and was discovered in 1827. Nevertheless its large-scale production only became a viable proposition in 1886, when Siemens developed the basics of heavy current engineering. For even today, smelting flux electrolysis is a necessity for the production of aluminium metal and this calls for high-voltage electricity. Not only this, the production of 1 ton of the metal aluminium in those days meant a requirement of 40,000 kWh, so that the metal was correspondingly expensive. For the reasons already mentioned, therefore, recycling was an obvious alternative: the enormous price and the highly coveted combination of characteristics and the “high mechanical strength and low specific weight” led to the construction of the first aluminium recycling smelters, the first one as early as in 1904 in the USA and then in 1917 in Germany. The rise in the consumption of aluminium is so unique that one is tempted to call the period after 1900 the aluminium age. Whereas just 2 t aluminium were produced worldwide in 1882, production lay at around 25 million t in 2000. To make the picture even clearer, for nearly 120 years there has been a permanent, moderate rate of increase in production of 15% per year.

A particular feature of aluminium is its reducibility. I have already said that electricity is required to produce metal aluminium from its oxide. In fact, the reason all classical metals have been in use for so many centuries is that they can be reduced from their oxides to metals at temperatures close to their respective melting points, using the reducing agent of our ancestors, charcoal. Unfortunately, it would take a temperature of about 2000°C to reduce the light metal aluminium, which melts at 660°C, from its oxide using charcoal.

![Ellingham diagram for the free energy of formation of metallic oxides](image)

This specific peculiarity was the reason our ancestors did not manage to discover aluminium as metal in spite of its unusually high concentration in the earth’s crust.

It is due to another specific peculiarity of aluminium - namely that together with a number of other elements, above all Si, Cu, Mg, Zn and Fe, it forms alloys of extremely different characteristics - that aluminium has taken such a leap in a space of only 100 years from being an admired rarity to the most significant metal second to steel. Because of the amazing variety of the characteristics of its alloys, aluminium is almost always used as alloy and not as pure metal. Consequently, the characteristics of alloys determine the sector in which aluminium is used. Because of its low specific weight, it now dominates the entire transport sector, from the car to the railway through to the aircraft.
The recycling of aluminium

When we speak of recycling aluminium, we always mean the recovery of its alloys. In terms of recycling, this involves a host of consequences, the most important of which I would like to outline briefly:

- The chemical composition of the aluminium alloys to be produced is standardized world-wide.
- The material used in recycling aluminium alloys is scrap i.e. metallic waste in various forms and compositions.
- It is technically not possible to use this alloy scrap in the primary production of pure aluminium.
- Consequently a separate aluminium scrap recycling technique has to be developed.
- Wherever aluminium is used, various combinations of aluminium alloy scrap is accumulated: a car will perhaps yield a cylinder piston with 14% silicon, and 1% nickel or an aircraft part will give sheet metal with 4% zinc and 1% magnesium.
- The products in the various fields of application have totally different life cycles. An aluminium beverage can will find its way back to the aluminium smelter after about 3 months, whereas it will take about 14 years for an aluminium cylinder block from a car to be returned, and an aluminium window frame from a governmental building might take 30 to 40 years to be returned – at which time the alloy standard composition possibly no longer exists. Since such scrap is accumulated only after a product’s life cycle, it is known as old scrap.
- Aluminium scrap is also accumulated when consumer articles are produced in the form of fabrication rejects or drilling or turning chips. Since this scrappage has never passed through the hands of a consumer, it is known as prompt scrap or new scrap.

So even for the professional, the recycling of aluminium presents a somewhat confusing picture. And I have to say it becomes even more complex when one realises that – to keep to the above example – not all used beverage cans from a production week are returned after 3 months. The first cans are emptied immediately and find their way after just a few days into the recycling works as scrap, whereas the last ones will perhaps turn up after a year. This means that all commodities become scrap with the passing of time, yet even today it is impossible to trace their respective distribution curves.

From the production of a particular model of a car, the first ones will literally be driven to scrap within a few weeks. The last models in this particular series will perhaps be given over to the scrap yard by their owner after 25 years. Possibly to the delight of the consumer yet somewhat exasperating for the recycling engineer, numberless models of a particular article are produced which can suddenly change in their composition from one construction year to the next. Given the distribution factor of the scrap feedback, the manifold nature of the commodities and the impressive variability in composition of the materials and their compounds, such changes become so incredibly interwoven that there are still no mathematical models to describe the recycling reality of even one metal such as aluminium, let alone make any reliable calculations for the future.

It is to this crass contrast between the word recycling, so suggestive of simplicity, and the sheer in calculability of recycling as resource of raw materials that I have devoted most of my career to date. And here I will be following it up academically and, as up to now, with total conviction.

For as Professor for Recycling Engineering I see my objective in lending transparency to the utterly inconvenient and, over the passage of time, dynamically changing recycling systems, maintaining this transparency in teaching and research, so that we will soon be in a position to calculate reliably just what the contribution of scrap can be for commerce and industry in the future.

With the circulating of aluminium, mother nature does not give mankind the opportunities of a perpetuum mobile. The aluminium cycle suffers deficits, meaning that aluminium is irretrievably lost to present-day technology and the economy. We can only minimise these losses; we will never be able to eliminate them. If we use aluminium metal to release liquid steel from oxygen, if we apply aluminium in the form of hydroxide to treat gastric, or if we use aluminium powder for the production of fireworks, then this aluminium metal is permanently removed from our recycling endeavours. When aluminium waste is melted, such as is the case with vehicle registration plates, frying pans, saucepans, cans, car engines or window frames, slag and filter dusts are generated that are of considerable measurable aluminium content. And this too is lost to the system.
Because of the outstanding properties of the various aluminium alloys, their use in the European production of cars has continued to rise. The 145 million cars now on Europe’s roads, admittedly sometimes only advancing at snail’s pace, constitute an aluminium inventory of some 10 million tons of metal.

Recycling as energy saver

In this respect, I would like to address an aspect of recycling that in the long term will be important. For the production of aluminium out of scrap, only 12% of the energy is required that is otherwise needed to produce the metal from its ore. If out of the 10 million tons aluminium inventory I have just mentioned from European cars, only 75% can be fed back into recycling, a savings of 1.1 billion MJ primary energy will have been made as compared to the primary production of aluminium. This saving would be enough to supply some 6000 Europeans with primary energy for one year. Another factor too is that in using this aluminium inventory from the road vehicles, some 50 million tons less CO₂ would be emitted into the atmosphere, not only because of the saving made, but also owing to the reduction energy still kept in the aluminium metal.

Conclusions

So let me summarise the insights gained from what is admittedly a compromised view of the use of our civilisation’s aluminium reserves:

- Recycling helps sustain raw material resources for future generations.
- Recycling sounds easy. As time-related circulation of material, however, it is dependent on subjective criteria which influence it and make it most difficult to shape.
- Consequently any prognoses on future material flows are founded on so many assumed simplifications, that they are quite simply useless.
- No less than 30 years ago it was considered rather “disgusting” to concentrate on scrap and was most definitely hardly worthy of an academically trained engineer. Today, the use of scrap is one of the most important tasks relating to mineral raw materials in a Europe which is otherwise poor in raw materials. For every European metallurgist it is quite simply a MUST.

I have already come to some conclusions for myself here at the TU Delft. I would rather like to present them to you such as they are – my own personal assessment of the situation.

Traditionally, metallurgy means the teaching of the production of metals from their raw materials – in the past, these raw materials were the ores.

Today, it is the metallic scrap that takes on increasing significance, particularly in respect of Europe that must now be seen as being low on raw materials.
Imaginative sciences have traced just where what mineral raw materials have been generated over millions of years, found out how they were composed and developed appropriate mining and melting procedures.

In future, metal scrap will have to be examined, among other things, for its form, composition and time-related accumulation, since it will undoubtedly be the new raw material of our times.

With the ores, the producer was mother nature. It was always traditional practice for the metallurgist to work together with the mining engineer and geoscientist.

Today, with the scrap, the producer is the manufacturing industry. Cooperation with this industry will be new ground for the metallurgist, but it will be imperative.

This industry will be represented by designers, constructors and manufacturers of commodities.

The way the material is used, its shaping, the technologies for combining a variety of materials will not only determine the life cycle but also the recycling quota of our commodities.

In order to be able to increase this quota, the metallurgist, together with the designer and constructor, will have to exert influence on the selection of the materials and on the future design of the commodities.

Here at the TU Delft, the constellation for this is particularly good, since there is a Faculty for Design, Construction and Production Processes, known by the abbreviation of OCP. And there is a Chair for Metallurgy, traditionally incorporated into the Faculty for Earth Sciences, known by the abbreviation of TA.

Because of this, a unique opportunity awaits us: that of incorporating the Chair for Metallurgy, which would not be entitled to exist in Europe any more without its focus on recycling, into the Faculty OCP, without having to throttle its traditional ties to the fields of mineralogy and mining.

In the past, our metallurgists were rightly expected to master the basics of recovering ore and concentrate. In like fashion, our future recycling metallurgists or resources engineers will have to master their future raw material of scrap and understand how it is produced – particularly since they will be in the unique position of influencing this considerably and will hopefully do so.

It is a source of tremendous satisfaction to me after many years of commitment to the subject of recycling to be appointed by the TU Delft to play my part in such a process of rethinking.

This does not mean cutting metallurgy away from its roots of ore processing but rather shifting the point of emphasis. As my last diagram illustrates, we will always need metals produced from their ores – yet society’s demand on us is to reduce the ore requirement, maximise the circulation of materials and leave as many raw materials as possible for coming generations.

This process of rethinking will play a trend-setting and exemplary part in future research and development in the Netherlands and in the training of the young resources engineers that Europe needs so badly.

Delft in January 2002

Fotos from BAS Brinker Aluminium-Schmelzwerk, Hanover