News & views

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Figure 1 | A reservoir of 'red mud'. This dam near the town of Alumínio, Brazil, contains 25 million cubic metres of hazardous waste from aluminium production.

Metallurgy

Iron extracted from hazardous waste

Chenna Rao Borra

Millions of tonnes of 'red mud', a hazardous waste of aluminium production, are generated annually. A potentially sustainable process for treating this mud shows that it could become a source of iron for making steel. **See p.703**

Steel and aluminium are the world's most-produced metals[1], but both have high environmental costs. The production of steel requires a fossil fuel (coal) and generates approximately 2 tonnes of carbon dioxide per tonne of steel[2]. Aluminium production generates 2–4 tonnes of environmentally problematic waste per tonne of aluminium produced[3]. On page 703, Jovičević-Klug *et al.*[4] report a process that has the potential not only to address this waste, but also to achieve carbon-neutral steel production — thereby increasing the sustainability of two major metal industries.

Aluminium is derived from alumina (Al_2O_3), which is obtained mainly by processing bauxite ore. Alumina production generates bauxite residue, commonly known as red mud[5]. Every year 180 million tonnes of red mud are produced, which has resulted in a stockpile of 4 billion tonnes[5]. Storage of this residue (Fig. 1) not only occupies valuable land but is also hazardous because of the material's high alkalinity and heavy-metal content. Although red mud can be used in cements, building materials and ceramics, these applications account for less than 3% of the amount produced[6].

Red mud consists mainly of oxides, including iron(III) oxide (Fe_2O_3), opening up the possibility that this waste material could be used as a source of iron. However, the production of iron metal from red mud is challenging because it requires various pre- and post-processing steps — such as neutralization, roasting, grinding and the removal of carbon, phosphorus and sulfur. Jovičević-Klug *et al.* now propose a fresh approach for extracting the iron.

The authors' approach involves exposing red mud directly to a plasma (ionized gas) of hydrogen in a furnace for a duration of 1–15 minutes (Fig. 2). In the initial stages of the process, the red mud transforms into a viscous melt. With time, the iron(III) oxide — which is thermodynamically less stable than other oxides in the melt — is chemically reduced by the highly energetic molecular, atomic and ionic hydrogen species in the plasma, thereby producing liquid iron and steam[7]. The liquid iron then separates as globules from the resulting slag, as a result of the difference in their densities. The reduction rate of iron in this type of process is higher than that obtained in reductions with hydrogen gas, owing to faster diffusion of elements and

From the archive

A lesson in mechanics that is required reading at many universities, and the eating habits of jellyfish.

50 years ago

The Mechanics of Athletics. By G. Dyson — Mr Dyson has vast experience of athletics and coaching, and makes clear at the outset his creed that the theoretical understanding of what one is supposed to be doing is the key to improvement ... Any athlete who has come to a steady state of achievement, yet nevertheless feels he ought to be able to do better, may well find the secret to his making fresh progress in the relevant chapters of this book. It has seen five previous editions, been translated into several languages including Japanese (who mean business in the sporting world, be it noted), and not surprisingly is required reading in many universities. It is hard to know how many readers of *Nature* may also be interested in athletics, but if they are not themselves, their children or friends may be, and whether or not these have access to coaching at high level, this book could well make an admirable scientific gift.
From *Nature* 25 January 1974

100 years ago

It is now well established that many of the smaller planktonic medusae catch and devour young fish. The fish are caught by the long outstretched tentacles, which react to contact with living organisms. The fish is stung, the tentacles contract, and with the assistance of other tentacles and the lips of the umbrella the food is conveyed to the mouth and digested in the stomach ... Medusae of one species do not as a rule eat each other, although they devour those of other species voraciously. If young fish are available, many medusae entirely neglect the smaller crustacea in the plankton. Others, on the other hand, appear to neglect the fish and restrict their diet to the crustacea. The amount and size of the food consumed by some medusae is very remarkable. In some cases the prey is much too large to be taken into the stomach, and partial digestion appears to take place in the region of the mouth, the liquid food being then sucked into the stomach.
From *Nature* 26 January 1924

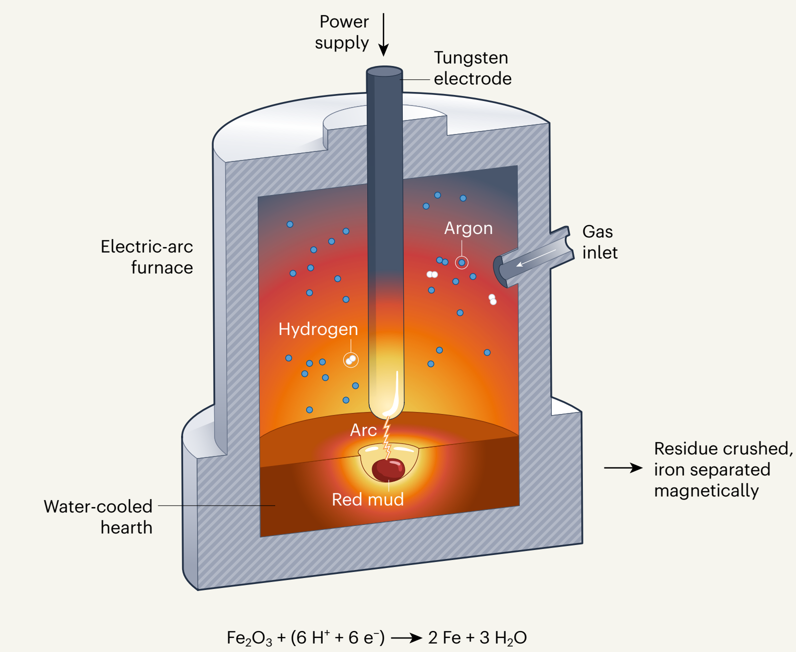

Figure 2 | Reduction of red mud by hydrogen plasma. Jovičević-Klug *et al.*[4] report a process for extracting iron (Fe) from red mud — a waste product of aluminium production that consists of iron(III) oxide (Fe_2O_3) mixed with the oxides of several other elements. The red mud is placed on a water-cooled hearth in an electric-arc furnace, which is flushed with a mixture of 10% hydrogen in argon. When a current is applied, an electric arc forms between the red mud and the electrode, heating the mud and ionizing the hydrogen to form a plasma. High-energy hydrogen species in the plasma react with the iron(III) oxide, producing liquid iron and steam. The iron forms as nodules in the resulting slag, and is isolated by mechanical crushing and magnetic separation. The overall reaction is shown; the hydrogen plasma is represented by a mixture of hydrogen ions (H^+) and electrons (e^-).

enhanced reactivity of the reducing plasma[7].

The authors studied the time course of their process, and observed that, during the first minute of the reduction, iron(III) oxide thermally decomposes to produce titanomagnetite ($Fe_{2.5}Ti_{0.5}O_4$), but only a small amount of iron metal is produced. However, by the tenth minute of reduction, approximately 70% of the iron in the original sample of red mud is converted to metal. Prolonging the process beyond 10 minutes leads to evaporation of iron. Overall, the authors showed that 2.6 grams of metallic iron could be extracted from 15 g of red mud — close to the theoretical limit that could be extracted on the basis of thermodynamic calculations.

Jovičević-Klug *et al.* conducted further characterization of the chemical evolution of the reduction. This revealed that the titanomagnetite produced during the first minute converts into hercynite (Al_2FeO_4), owing to the high amount of alumina present in red mud, and finally into iron metal. Notably, an earlier study[8] by some of the same authors as Jovičević-Klug *et al.* found that wüstite (FeO) is formed as an intermediate compound in the reduction of pure iron (III) oxide by hydrogen plasma. By contrast, wüstite was not observed as an intermediate in the present study. The authors suggest that the pathway observed in the current study is catalysed by the presence of other oxides in the red mud.

Because the reported reactions were carried out on a multigram scale, Jovičević-Klug and colleagues conducted a cost analysis to show that the process would be economically viable at an industrial scale. However, pilot-scale studies will be required for a truly reliable cost assessment. Analysis of the fumes produced by the process will also be needed, along with recommendations for how these fumes could be either used or safely disposed of. The cost analysis used the stoichiometry of the reaction to calculate the hydrogen requirement. However, in practice, more hydrogen is flushed through the furnace than is accounted for by the reaction stoichiometry and the excess would need to be recovered, purified and reused to ensure sustainability.

The authors' method has several benefits: it is a straightforward, single-step process that extracts iron without the need to pre-process red mud. It is potentially energy-efficient and sustainable, and it yields high-purity iron with small amounts of undesirable elements such as carbon, phosphorus and sulfur — which means that the iron is suitable for steel production without further substantial refining. Furthermore, the residual slag produced during the process is neutral (neither acidic nor basic) and could be used as a building material.

More broadly, the general approach of hydrogen-plasma reduction is versatile and potentially applicable to other materials. The next step should be to investigate its use for extracting iron from resources such as low-grade iron ores and the waste (tailings) from the processing of iron ore. These resources are available in even greater quantities than is red mud, and some of them, such as iron-ore tailings, are equally hazardous to store.

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Economics

Urban youth most isolated in largest cities

Victor Couture

GPS data reveal that young people encounter fewer individuals from diverse groups than do adults. The isolation of young people is exacerbated in larger cities, and for those living in poverty.

Cities exist to bring people together. Shared urban spaces, such as public amenities or commercial venues, offer settings for social interactions – be they for networking, learning or friendship. But the social benefits offered through such interactions are not open to everyone. Writing in *Nature Cities*, Cook *et al.*[1] report that young people living in urban areas often struggle to take full advantage of the benefits of large cities. For instance, young people living in poverty tend to visit venues close to their homes, which are typically frequented by people with similar incomes. The authors' extensive evidence echoes anecdotal accounts, such as those of disadvantaged youths who live in Los Angeles, California, but have never seen the ocean (see go.nature.com/3rpkj3v).

Cook *et al.* used GPS data to document the varied social experiences of people from different demographic groups in the United States. These experiences can be quantified through measures such as racial isolation, which captures the extent to which people from minority groups visit the same shared spaces as those frequented by the majority group. However, GPS data for smartphones capture only the movement of the device, not the characteristics of its owner. Quantifying racial isolation and the closely related measure, income isolation, therefore presents a considerable challenge, which the authors addressed by developing ways of assigning income, race and student status to devices in their sample.

Device owners were assigned a home location on the basis of where their device was at night, and their income group was inferred from data on housing value. The authors gauged whether a device owner was white or non-white from the racial composition of the census block group (the smallest geographical unit used by the US Census Bureau) corresponding to their home location. Individuals were designated as students if the device was frequently at a school on weekdays. Devices belonging to individuals under 16 years old were excluded, so student age ranged from 16 to 18 years old. In this sense, the study uses student status as a proxy for youth.

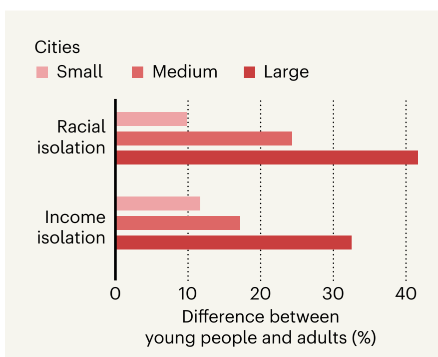

Figure 1 | Isolation experienced by urban youths compared with adults. Cook *et al.*[1] used GPS data to categorize smartphone owners on the basis of their income, race and age. They then quantified the racial and income isolation (which capture the extent to which people encounter members of other groups in shared spaces) experienced by each device owner. They found that young people experience more isolation than adults do, and that the difference between the two groups increases with city size. (Adapted from Table 2 of ref. 1.)

These methods allowed Cook *et al.* to attribute a demographic profile to the owner of each device, and to people in the venues they visited. They used a previously developed measure[2] of income isolation to capture how often people with different incomes are in the same shared spaces. Specifically, an income isolation level of 0.5 means that there are half as many high earners in the venues that low earners visit, on average, as there are in the venues frequented by people with high incomes. Racial isolation is defined similarly.

The disparity in isolation between young people and adults is stark: young people face 21% more racial isolation and 13% more income isolation than do adults. Intriguingly, the gap between these two groups becomes more pronounced in larger cities. Young people in small cities experience around 10% higher racial isolation than do adults, whereas the difference in the largest cities is about 42% (Fig. 1).

Why are urban youths so isolated? Cook *et al.* found that young people spend more time than adults in and near their their homes – a tendency that increases isolation if neighbourhoods are segregated by race and income. Adults typically have more varied daily routines, such as going to retail outlets and restaurants. Adults also tend to have more economic resources, including access to a car, which allows for broader social interactions across the city. This finding offers a nuanced view of how different demographic groups engage with their urban environment. Low-income youths with constrained mobility rarely interact with high earners, and might therefore be missing out on some of the social benefits of living in large cities.

Indeed, the importance of forming local interactions with high earners has already been made clear. A study showed that an individual's upward social mobility can be predicted from how many of their Facebook friends come from affluent backgrounds[3]. And a study that used GPS data demonstrated how interactions in shared spaces can lead to job opportunities[4]. The benefits of socializing with high earners are often not available to youths from low-income backgrounds, who are most in need of urban opportunities but have restricted exposure to people outside of their socio-economic circle.

Clearly, the mere presence of shared urban spaces does not guarantee diverse interactions