1 Material wealth and health

What are we worried about?

In developed economies we live the good life for now – with an amazing level of comfort and interest created by our astonishing ability to make and transform materials. We've really only done this at scale in the past 150 years, in which time our use of engineered materials has rocketed, literally. However, if we have some concern about 'sustainability' we need to anticipate what effects our use might have on future generations – and we're getting some clear indicators that there's a problem.

Welcome to this edition of "The World's got Materials" and we'll go straight into the first round: name the first thing that comes into your head when you hear the following place names: you must answer immediately. San Francisco, *Golden Gate Bridge*; Paris, *Eiffel Tower*; Hong Kong, New York and Shanghai, *skyscrapers*; Sydney, *Harbour Bridge*; North Pole, *pole*. Excellent. A perfect score, so we'll move straight on to the second round: for each of the following decades name its key icon. 1960's, *moon landing*; 1970's, *cassette decks and VCRs*; 1980's, *personal computers*; 1990's, *internet*; 2000's, *mobile phones*. Very good, albeit a little selective, and finally in the third round, tell us how you spend most of your money: *housing; car and other travel; food*. Congratulations! A perfect set of answers and, apart from some of the food everything you've mentioned depends on energy intensive materials.

A Bessemer converter in which hot air is blown through liquid iron to burn off impurities and so produce cheap, malleable steel

We learnt at school the progression from stone age, bronze age, iron age through the dark and middle ages, age of discovery then enlightenment and on to machine and information ages. But we could equally label the past 100 years, our era, as the material age. Our ability to find and convert fuels into intense heat has allowed us to extract and convert natural ores and minerals into the metals, ceramics and polymers with which we have constructed all our recent icons and inventions, and on which we spend most of our money. This phenomenon is so common, and largely so well hidden, that we are hardly aware how recent it is: Joseph Aspdin in Leeds first patented the production of Portland Cement, the basis of modern concrete and mortar, in 1824; Henry Bessemer in Cheltenham patented his steel making process in 1855; Charles Hall in Ohio in 1886 and simultaneously but independently Paul Héroult in Paris worked out how to produce aluminium cheaply. These inventions, all occurring during the lives of our grandparents' grandparents, and their equivalents for plastics and industrial paper production, transformed the economics of materials from precious to commodity, and opened

the door to our current remarkable dependence on materials. In just over 100 years, global production has grown from virtually nothing at the turn of the 20th century to the point that we now make more than 10 times our body weight of these five materials every year, for every person alive.

Our primary use of materials has been to live in more comfort in much higher densities, while travelling much greater distances. In the past 100 years we have shifted rapidly from rural to urban dwelling, and can sleep, work and relax in remarkable comfort in cities, solely because we have the materials to build, heat, cool and light safe interior spaces at high density and to travel rapidly and comfortably between them. In fact, such is their attraction that in 2009, for the first time in history, half the world's population lived in cities. Worldwide, we now have 21 mega-cities, with more than 10 million people each, housing nearly a tenth of the world's population[1]. And although large cities appear to be efficient, moving people to cities tends to increase economic growth, both within the city and in the surrounding rural areas, leading to an increase in demand for materials.

The clocktower of the Palace of Westminster, which houses *Big Ben*

Making, transforming and buying these fantastic materials uses a good deal of our money. Around one third of a billion people worldwide[2], 5% of all of us, are directly transforming the materials for us and 10% of our collective spending goes to the companies who make these materials.

All of this sounds terrific: what fortunate people we are to have such apparently unlimited access to such high-quality but cheap material that we use to create such a great lifestyle. No one has ever lived like us before. We are the lifestyle kings and queens of history!

But of course no fairytale is worth telling if there isn't a villain—without the wolf, we'd remember neither Little Red Riding Hood nor her grandmother—and this book exists because there are several baddies roaming around our material world. To find out more, where else could we turn other than to the BBC who introduce their evening news programme with the sonorous bongs of Big Ben (13.5 tonnes of cast iron, made at the Whitechapel Bell Foundry in 1858):[3-6]

12th October 2010

Villagers despair in Hungary's red wasteland

Around 600,000 tonnes of toxic red mud, a by-product of washing bauxite in sodium hydroxide to create alumina, covered around 40 square kilometres, may take a year to clean up. The accident injured more than 150 people and has claimed 10 lives. Hungary's Ajka Alumina Plant produces around 0.5 % of global alumina output.

20th October 2010

Rio Tinto in $3.1bn Australia iron-ore expansion

Typically we extract about 10 tonnes of iron sands to yield 1 tonne of ore, so if the sands are in a band about 10 metres deep, and have a density of 5 tonnes per cubic metre, Rio Tinto's Australian production uses up about 560 square kilometres of Australia each year—equal to about half the land area of Hong Kong.

4th January 2011

China to restrict exports of rare earth elements

China currently produces around 97 % of the global supply of rare earths (elements we use in making permanent magnets, used in some electric motors and generators, particularly in wind turbines) so could limit development of these products elsewhere, unless other supplies are found.

9th March 2011

Polar ice loss quickens, raising seas

Satellite imaging demonstrates that ice loss from Antarctica and Greenland has accelerated in the past 20 years, due to global warming, and sea levels are rising faster than anticipated by the Intergovernmental Panel on Climate Change (IPCC) in its 2007 assessment.

It's getting a little noisy, so we'll cut off Big Ben, and reflect on the range of issues which are causing us concern about our escalating demand for materials:

- **Resource shortages**: clearly the world must eventually run out of minerals and fossil fuels, but that point is a long way ahead. The more pressing challenge related to resource shortages is that we are using up the best deposits, so in future will have to invest more money and energy in exploiting less convenient sites. This will drive up prices and may create conflict due to the uneven geographical distribution of the resources.

- **Water stress**: possibly more pressing than mineral shortages is parallel concern about fresh water. Globally we are not short of water, there is plenty. However in some places, we are short of water of the quality we would like. For poor areas, there is no solution except for people to move. For rich areas, such as the state of California, water can be transported by (energy intensive) pumping, or in Malta, fresh water is made from the Mediterranean by (energy intensive) desalination. Some aspects of materials production are water intensive, increasing the potential for local water stress.

Shanghai

- **Land stress:** there is a limit to how much more land can be brought into agricultural production, so any use of land to generate bio-fuels is likely to be at the cost of land used for some other valued purpose.

- **By-products and toxic chemicals:** for most ores, we have to extract ten tonnes of rock to gain one tonne of ore, and then we need to extract the element of interest from the ore. This extraction requires energy, but also the use of chemicals, some of which are harmful. Most are regulated and well controlled, but as we saw in Hungary, accidental releases will occur. As we don't know the long-term consequences of releases of all chemicals, it is difficult for regulators to know that they have set safe levels. Emissions of chemicals to soil, water and air can have a wide range of harmful effects on different species.

- **Climate change:** the greenhouse effect has been known and understood since John Tyndall's experiments published in 1858, and is undisputed. The sun's rays fall on the earth, which radiates back some of their energy, at a different frequency. Greenhouse gases in the atmosphere absorb some of this reflected radiation, and re-radiate it in all directions, including back towards the earth. The greenhouse effect thus causes the earth to warm up. The greenhouse gases include most gases with two different atoms and all with three or more, of which the most important is carbon dioxide (CO_2). Burning fossil fuels, coal,

Bauxite mining in the Amazon rainforest

gas and oil, releases CO_2 into the atmosphere, so increases the strength of the greenhouse effect, and hence causes global warming. All of this is undisputed fact. However, there remains debate about man-made global warming, not because of these facts but because (a) we have only partial records of greenhouse gas concentrations and global temperatures over both space (i.e. throughout the atmosphere) and time, (b) the climate is subject also to many other effects, not all of which are fully understood and which are difficult to forecast, and (c) there is a lot of misinformation around, and various groups are motivated to increase it. The Intergovernmental Panel on Climate Change (IPCC), whose 2007 Nobel Prize winning 4th Assessment Report has been widely examined (and to us it is most remarkable not because a small number of errors were found, but because the number of errors was so small), claims that "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." As a result, the IPCC recommends that global emissions of greenhouse gases should be cut, by 2050, to 50%-85% of 1990 levels, to limit the global average temperature increase to 2.0–2.4°C and avoid the adverse effects of climate change.

These concerns are all real, serious, and pressing. The world's population has more than doubled in the past 50 years, and our use of engineered materials has increased by 4 to 15 times in the past 50 years. All the issues we've raised are driven by the volume of production of materials: if we double production, and make no other changes, we will double the drivers of each concern.

However, this book is not about gloom. We've been motivated by these concerns to look for implementable practical changes that will reduce the likelihood that our own actions seriously degrade the quality of life that generations after us can enjoy. With that ambition, we join a whole raft of others who sail under the banner of "Sustainability" and that's a mixed blessing. The pioneers who have raised awareness about the problems we've listed above are heroes without whom we wouldn't have started. Defining the problem—of climate change, sustainability or, environmental impacts—is not what we're about, because that's been done well, and ongoing work by others is improving our ability to forecast consequences.

Instead, our aim is to look at solutions, and our number one guiding principle is about scale—we want to make sure that we identify options for change that are big enough to make a big enough difference. In fact the whole of our next chapter discusses scale, so no more on that for now. However, given that many others have

Mining iron ore

written about solutions, before we set off with our search for solutions, and very delicately, we'd like to say briefly what we're not:

- We're not promoting an ideology. We've read several books where the authors claim to have found the answer, "Do what I say, and use my catch phrase, and we can all get there, yee-ha" and so on. The difficulty about these books is that they all seem to validate their claims by showing that passive houses use less energy than conventional houses. We know that, but if we look at the third of the world's energy that's required to make and form materials, we have to look at more than just domestic heating.

- We're not actors within industry and we're not a lobby, so we can explore all possible options including those that don't involve growth. This is vitally important. Nobody employed in industry can be seen to explore the option that their industry should shrink. That's obvious—but for the materials producing industries, who are also the main sources of data on the impacts of materials production, there is a danger that they might only inform governments about options which allow further expansion of the industry, so the idea of reduced output will never be considered.

- We're not a national government. Presumably that's obvious, but it's very important, because it means we can't pursue solutions that shift the problem elsewhere. Our former Prime Minister Tony Blair was the first to sign up for the Kyoto Protocol. Broadly that's good and we wish everyone else had done so, but he did it in the knowledge that we'd already met the target, by a combination of switching from coal to gas powered electricity generation and by continuing Mrs Thatcher's policy of allowing manufacturing to shift off the shores of the UK. The shifting part has obviously had no effect on global emissions because the activity continues elsewhere, so we have to be very careful about national emissions figures.

The authors

What we are is a research team of eight at the University of Cambridge, who have been funded[7] for five years to explore sustainable materials. The main focus of our work has been on steel and aluminium production and its emissions of CO_2, but we think we have learnt enough to expand our remit to the three other key materials, and to demonstrate that the options that would lead to a cut in emissions will also be the main options required to address most other concerns about future sustainability. We only put two of our names on the front cover of the book so it didn't look too much like a take-away menu, but the eight of us in the photo have shared the learning and the work leading to this book.

So our aim in this book is to explore all possible options for creating a sustainable materials future, and as much as we can, to present a rational evaluation of how difficult it would be to implement them. An over-riding concern in our work has been to examine the whole picture and because scale is so important to us, that's the focus of the next chapter.

And although we're not selling an ideology, an important discovery in our work has been that there is a whole raft of options for creating a sustainable material future which have had very little attention. Material efficiency, using less new material to achieve the same goals, is a rich opportunity. We've used the phrase "with both eyes open" in our title as a reminder that, as well as making materials efficiently, we can also make less of them. We particularly want to raise awareness of these options, so as well as writing the book for a broad audience and making it freely available online, we've also written a set of songs on the theme. We've spread a few song fragments through the book, and have been fortunate to persuade Adey Grummet, star of Cats, Les Miserables and D'Oyly Carte to record them for us. You can hear Adey, find out more, and download chapters of the book at www.withbotheyesopen.com.

Notes

1. The United Nations Population Fund (UNPFA) publishes a State of the World Population Report every year, which includes demographic, social and economic indicators, by country and region. Figures in this section were taken from the 2010 report (UNPFA, 2010). The United Nations also has a Population Division in the Department of Economic and Social Affairs which reports urbanisation figures, (UNDESA, 2009)

2. We will look in more detail at who's involved in transforming materials into products in chapter 6.

3. The BBC article "Villagers despair in Hungary's red wasteland" BBC News, 2010a) describes the release of toxic "red mud" from a holding reservoir in Ajka, Hungary. The Ajka Alumina Plant is owned by MAL Hungarian Aluminium and is licensed to produce 300,000 tonnes of alumina per year, according to Jávor and Hargitai (2011). The plant was originally established to process bauxite ore to alumina to feed Hungary's aluminium furnaces for metal production. However, because of the closure of these furnaces and rapid growth in demand for non-metallurgical alumina the Ajka plant has not produced alumina for metal production since 2006. The International Aluminium Institute (IAI) provides annual statistics on alumina production and estimates the 2010 global production of alumina to be 56.3 million tonnes: 51.6 Mt for metallurgical uses and 4.7 Mt for chemical uses (IAI, 2011b). Thus the Akja Alumina Plant contributes 0.55 % of total global demand for alumina (but 6 % of alumina for chemical uses).

4. Reported on the BBC website: Rio Tinto in $3.1bn Australia iron ore expansion (BBC News, 2010b). The land area calculation is conservative, as it excludes mining infrastructure such as access and haulage roads and processing facilities. Rio Tinto recently signed agreements with Aboriginals to gain iron ore mining access to 71,000 square kilometres of land in Pilbara, Western Australia (BBC News, 2011a). The deal will allow Rio Tinto to expand their iron ore operations in Australia to 330 million tonnes by 2015, a 50 % expansion on 2009 levels.

5. Based on a debate on BBC Radio 4's Today Programme, with Dr Richard Pike, of the Royal Society of Chemistry and Mark Leonard, of the European Council on Foreign Relations (Pike & Leonard, 20aa).

6. From an article by the BBC's environment correspondent, Richard Black, "Polar ice loss quickens, raising seas" (Black, 2011).

7. Nearly all the funding for our work has been provided by the Engineering and Physical Sciences Research Council (EPSRC) of the UK through a 'Leadership Fellowship' awarded to Julian Allwood. The funding has no pre-conditions. One of us is funded by a PhD studentship three quarters of which is paid by the EPSRC and one quarter by Arup, but our agreement with Arup is about confidentiality only. Our work has been supported by a consortium of more than twenty large companies, with whom we've met frequently to discuss all aspects of the work in this book. Much of the evidence presented in the book has been gathered in collaboration with them, but the interpretation is our own. More details about our ongoing research are on the project website, www.wellmet2050.com.

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