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Material efficiency: A white paper

Julian M. Allwood [a,*], Michael F. Ashby [a], Timothy G. Gutowski [b], Ernst Worrell [c]

[a] Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, United Kingdom
[b] Department of Mechanical Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139-4307, USA
[c] Department of Environmental and Innovation Studies, Utrecht University, Heidelberglaan 2, NL-3584 CS Utrecht, The Netherlands

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ABSTRACT

For most materials used to provide buildings, infrastructure, equipment and products, global stocks are still sufficient to meet anticipated demand, but the environmental impacts of materials production and processing, particularly those related to energy, are rapidly becoming critical. These impacts can be ameliorated to some extent by the ongoing pursuit of efficiencies within existing processes, but demand is anticipated to double in the next 40 years, and this will lead to an unacceptable increase in overall impacts unless the total requirement for material production and processing is reduced. This is the goal of material efficiency, and this paper aims to stimulate interest in the area. Four major strategies for reducing material demand through material efficiency are discussed: longer-lasting products; modularisation and remanufacturing; component re-use; designing products with less material. In industrialised nations, these strategies have had little attention, because of economic, regulatory and social barriers, which are each examined. However, evidence from waste management and the pursuit of energy efficiency suggests that these barriers might be overcome, and an outline of potential mechanisms for change is given. In bringing together insights into material efficiency from a wide range of disciplines, the paper presents a set of 20 open questions for future work.

1. Introduction

Engineered materials are abundant and life as we currently live it would be impossible without them. Since the industrial revolution, we have processed these materials in an industry operating mainly as an open system, transforming resources to products that are eventually discarded. However as a result of growing demand, mankind now dominates the global flows of many elements of the periodic table (Klee and Graedel, 2004), selected materials have become scarce, and access to materials affects the security of many nations. An expanding population living on finite resources is always in danger of consuming all its resources and according to Diamond (2006), resource expiry may account for the collapse of several past civilisations. In addition, materials production and processing have dramatic impacts on the environment, including land use patterns, the use of water, undesirable emissions to air, water and land and the consumption of other important environmental resources. The risk of catastrophic climate change due to emission of greenhouse gases (GHGs) is currently seen as an urgent threat, and the basis of industrial development in its current form is challenged by the need to reduce GHG emissions by 55–85% by 2050 (Fisher and Nakicenovic, 2007, Table 3.10, p. 229).

This paper concerns a set of opportunities, which we term ‘material efficiency’, that might provide a significant reduction in the total environmental impact of the global economy, but which are underdeveloped. Material efficiency means providing material services with less material production and processing, and Fig. 1.1 contrasts the approach of material efficiency with the ongoing pursuit of energy efficiency in the energy intensive industries. Our focus is on engineering materials – those used to create buildings, infrastructure and goods, and excludes the use of hydrocarbons for fuel. We distinguish our interests both from those of resource efficiency (where all resources are measured with a single weight measure) and from product based approaches (often driven by Life Cycle Assessment studies, where it is unclear whether improvement to a particular product has any global significance). By focusing on global use of key materials we aim to identify changes that could make a global impact.

Material efficiency was normal practice prior to the industrial revolution, as the relatively high value of materials compared to labour ensured that buildings and products were maintained, repaired and upgraded. However, since concerns over the environmental impacts of post-industrial revolution production have risen to prominence, material efficiency has received limited attention in contemporary analysis and policy. The ambition of this paper is therefore practical: to survey the wide range of interests that intersect the area; to clarify and organise the evidence we already have; to identify the key open questions whose solution will

* Corresponding author. Tel.: +44 1223 338181; fax: +44 1223 332662.
E-mail address: jma42@cam.ac.uk (J.M. Allwood).

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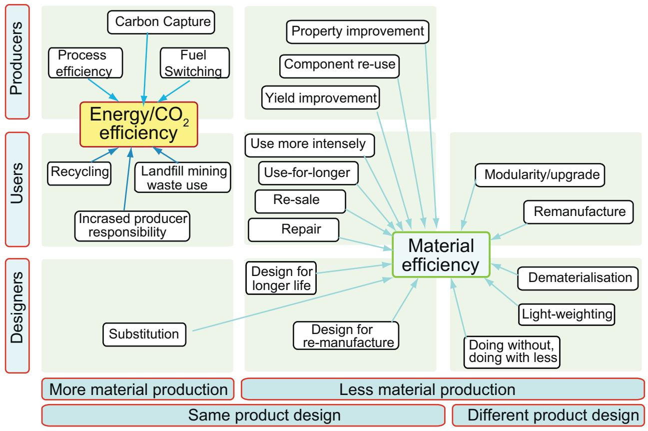

Fig. 1.1. Material efficiency contrasted with energy efficiency.

lead to widespread implementation; to stimulate activity in this area.

2. Is there a need for material efficiency?

Global demand for engineering materials has quadrupled in the past 50 years as shown in Fig. 2.1 and is currently growing at its fastest rate. The International Energy Agency (IEA, 2008a), based on assumed population growth to over 9 billion, and economic growth giving per capita wealth three times greater than the present, forecasts that demand for materials will by 2050 be at least double current levels. This section examines whether this level of demand can be met and if so, whether it can be met without unacceptable environmental stress. If not, material efficiency which aims to provide material services with less material production must be a key response.

2.1. Will we run out of material?

Engineering materials originate from oil (polymers), ores (metals and ceramics) and biomass (timber and paper). The earth's supply of oil and ores, which are non-renewable will eventually be exhausted to the point that their cost exceeds their utility, so the question of whether we will run out of materials can be rephrased as:

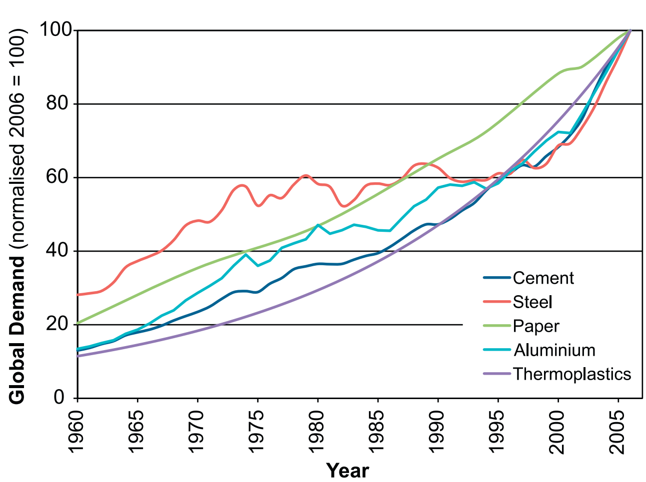

Fig. 2.1. Normalised demand for five key materials 1960–2005. From Allwood et al. (2010).

- When will the difficulty of extracting (non-renewable) oil and ores drive prices to a level that significantly constrains our use of them?
- What rate of use of (renewable) biomass as an engineering material (as opposed to food or fuel) is biologically sustainable?

The criticality of *oil*, particularly the prediction of 'peak oil' – the date beyond which annual oil production declines, has been subject to extensive research. de Almeida and Silva (2009, Table 1) compare 30 predictions of peak oil made since 2000, showing wide variation with several authors predicting a peak before 2020, but some denying that a peak will occur at all. These latter predictions assume that production will expand to match demand, and are derived from forecasts of future GDP. The more credible predictions are based on estimates of physical reserves of un-extracted oil, but these still vary widely. Bentley et al. (2007) explain this discrepancy based on the difference between oil companies' reports of 'proven reserves', which are influential in share price valuation but are dependent on extraction costs, and physically based 'proven and probable' reserves which estimate the remaining contents of each field. Aleklett et al. (2010) in a detailed critique of the '2008 World Energy Outlook' (IEA, 2008b) estimate that 'peak oil' has now occurred, that production from conventional fields will decline, and even with increasing output from new and unconventional sources, total production will decline from ~80 Giga-barrels (Gb)/day now to ~75 Gb/day by 2030. The impact of this on future polymer production is difficult to estimate: demand for oil for transport would grow if not supply-constrained, so declining production will drive up prices. However, the supply of oil for conversion to polymers is secure for the foreseeable future, albeit at increased cost.

The simplest predictor of *ore* criticality is the static index shown in Fig. 2.2. However:

- The definition of 'reserves' in Fig. 2.2 is pessimistic, as it includes only known deposits that could be extracted profitably with current technology. As these reserves are used, prices will rise, so other technology will become profitable and the motivation to identify and exploit other sources will increase. Where estimates are provided, the figure also shows the index based on 'resources' – the total known supply – which is much greater.
- The static index in Fig. 2.2 assumes that demand in all future years will be the same as this year. This is unlikely, and an alternative view taken by Meadows et al. (1972) is that demand will grow exponentially, so the static index is over-optimistic.

The prediction of future ore shortages thus depends on trading off assumptions about future resource discovery and extraction, against those of future demand. Ericsson (2009) examined these trade-offs for the global non-ferrous metals industry, and showed that over a sustained period, exploration spending has been proportional to metal prices. From 2000 to 2008, metal prices rose rapidly, but despite the associated increase in exploration spending, the rate of discoveries of significant new deposits declined. He attributes this to the fact that most easily detected ore bodies have already been located, so exploration of more remote regions or for less easily detected sources is costly. Graedel (2009) goes further claiming that 'most of the likely locations on Earth have now been explored [so] it is unrealistic to anticipate that major new ore deposits lie hidden.' However, the evidence on 'resources' rather than 'reserves' in Fig. 2.2, and the many references in USGS (2010) to minerals in ocean water, suggests that the problem is not an absolute lack of supply, but in the increasing energy and monetary cost of extracting useful minerals from less concentrated sources. This increase in cost could lead to critical shortages of particular minerals and a first attempt to examine this criticality has been made for 11 materials in the US economy by Eggert et al. (2008)