What are the opportunities for the engineer to contribute to the sustainability of materials?

Some thoughts – Dan Cooper, May 2013

1. A Kaya identity for emissions associated with a material
2. Opportunities to contribute
3. Frustrations faced
4. Overcoming the frustrations

There is an immediate opportunity for engineers to contribute to the sustainability of materials by increasing the boundaries of their analyses (in both space and time), connecting business and consumer activities to global effects. Such an approach would clarify the impact of this activity, and enable identification of which changes would have the largest environmental benefit. The sustainability of materials, though, depends upon a wide range of disciplines. The areas in which engineers are well placed to contribute – such as the decarbonisation of the energy supply, the energy efficiency of material production, and the material efficiency of manufacturing products – interact with population, GDP and social/personal wants, and it is their combination that determines our effect on the planet's natural capital. It is, therefore, only through collaboration with demographers, economists and social scientists that a cohesive strategy for sustainability can be created.

Of the various approaches to sustainability, environmental sustainability – minimizing climate change and preserving natural capital – has become the most well known, and pollutants recognised as large economic externalities. (For the sake of concision, 'sustainability' from this point will be used to refer to environmental sustainability.) To demonstrate how engineering, demography, economics, and social science influence sustainability, Figure 1 presents an adapted Kaya identity[1], showing a calculation for global CO2 emissions. Whilst sustainability does not only refer to a reduction of carbon emissions, analogous identities could be produced for many key pollutants.

$$CO_2\ Emissions = Population \times \frac{Services}{Population} \times \frac{Material}{Services} \times \frac{Energy}{Material} \times \frac{Carbon}{Energy}$$

Figure 1: A Kaya identity for the carbon emissions associated with using a material

Only three of the five terms in the identity are traditionally associated with engineering: energy supply, energy efficiency, and material efficiency. Mackay's book *Sustainable Energy: without the hot air* (2008) examines decarbonising the energy supply, concluding that renewable energy sources' large land requirements make them unrealistic options for densely populated nations, but that politically unattractive nuclear power plants present good opportunities for reaching this goal. In light of this, engineers can assist in decarbonising the energy supply by continuing to examine appropriate uses for renewables and by improving the safety of nuclear power plants and waste to encourage greater adoption. The challenges in moving from a fossil fuel based energy supply are immense, and the problems associated with industrial and energy transitions are well documented in Smil's *Prime Movers of Globalisation* (2010). It should also be noted that steel, the production of which accounts for twenty-five percent of industrial carbon

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[1] The **Kaya identity** is an equation relating factors that determine the level of human impact on climate. The identity was developed by Japanese energy economist Yoichi Kaya in 1993.

emissions, is initially produced by reducing iron ore with carbon monoxide derived from coke, directly producing carbon dioxide. Therefore, decarbonising electricity generation would not prevent carbon emissions from primary steel making. Electrolysis technologies for the production of steel are in progress, but currently in their infancy.

Finding means to improve energy efficiency has dominated material producers' research, as energy is a large proportion of their costs. Although engineers can make considerable improvements in this area, Gutowski et al[2] have shown that projected gains will not meet the IPCC's recommended emission cuts. The inability to reach these targets by energy efficiency improvements alone has recently prompted research into material efficiency (delivering services with less material production). There are some traditional engineering disciplines to exploit here: reducing yield losses in manufacture and light weighting of products, for example. Flexible manufacturing is both energy and material efficient, involving the replacement of heavy tooling with precision-guided tools on multiple axes, allowing removal and forming of material. The absence of heavy tooling may directly save energy in manufacture by reducing inertial forces, though these savings are small as the actuators are rarely optimized to work at their most efficient operating point. The process' flexibility means that new tools are not required for new designs and there is the possibility of compensating for tool wear (especially when using closed-loop control), making the tools last longer. Flexible manufacturing also permits bespoke optimised components to me made, removing the need to use stock parts.

Despite considerable research into decarbonising energy supplies and improving energy efficiency, global emissions have continued to rise. Behavioural changes – such as car sharing – could reduce emissions without technical challenges, and engineers have completed comparative studies to highlight this. Many material efficient strategies are not economically viable for businesses at present, and so are not taken up. Though this failure to alter can be a source of frustration, sustainability engineers can highlight the positive impact such changes would have through university education and communication with the public.

Though engineers could easily believe that efforts towards increasing sustainability are being thwarted by consumer apathy and corporate profit motives, it is important to note that engineers typically consider each of the terms in figure one to be independent. In reality, socio-economic and engineering factors are interdependent, the most famous illustration of this being Jevon's paradox – that increasing energy efficiency leads to lower costs and an increase in total consumption of a resource. Therefore, it may not be the case that the take-up of material efficient strategies motivated by the free market would lead to a reduction in emissions. Similarly, the money an individual may save by car sharing could be spent on carbon intensive services and products, such as long distance flights. It is clear that the ideal boundary for sustainability analyses would encompass all the disciplines highlighted in figure one (if not more). Practically, sustainability engineers should maximize the boundaries of their analyses, to encompass as much of the engineering system as possible (for example, any analyses focusing on one area of steel should also consider the effects on use phase emissions and the whole steel material flow). Beyond this, they should seek to appreciate demography, economics, and social sciences and collaborate with experts in these fields: collaboration is the most likely method of producing an informed analysis of the whole picture of sustainability. By working with policy makers, the media, and businesses, engineers and their collaborators can contribute greatly to the sustainability of materials.

[2] Gutowski T.G., Sahni S., Allwood J., Ashby M., Worrell E., "The Energy Required to Produce Materials: Constraints on Energy Intensity Improvements, Parameters of Demand," submitted to Phil. Trans. R. Soc. A.

To organise such large scale collaboration, central organisation – though unpopular in liberal economics – may be necessary if sustainability is to be achieved. Profit and loss (through the price mechanism) is often seen as providing the most rapid feedback on the financial worth of one's actions. In the field of sustainability, however, actions by individuals that appear, and are intended, to be sustainable – but which in reality are not helpful – may continue to be practiced because there is no feedback comparable to that found in the rest of the economy to provide a measure of such actions' success. This lack of immediate financial feedback means that studying the interaction between local and global effects is crucial to understanding the true value of any exploits that seek to increase sustainability. Only through connecting local actions to global effects, therefore, by using large boundary systems analysis, can we both have confidence in the true impact of our actions, and identify which steps provide the greatest environmental gains and warrant government funding.