Rethinking the economy

Roland Clift and **Julian Allwood** outline how industrial ecology can point the way to a more sustainable economy

IF we accept the need to reduce our emissions of greenhouse gases (see also p27), it is clear that we urgently need to decarbonise the energy system and reduce our energy use. Policy in the UK, as in many other countries, has so far focussed on improving the energy efficiency of industrial processes which provide materials and products. However, the scope for improving industrial energy efficiency is limited: industrial processes have always been subject to cost pressures to optimise performance. So we need to approach the problem differently, focussing on how to reduce flows of materials through the economy. This does not necessarily mean having fewer material goods in use; rather, it means managing materials more intelligently. The ideal model is the "closed-loop economy", an idea which governments (including the European Commission and China) are now supporting. However the idea of closed-loop material use is by no means new. It is at the heart of the concept and approach known as industrial ecology, which is the application of chemical engineering thinking to the management of material flows in the economy.

re-engineering performance

Part of industrial ecology involves analysing the flows and stocks of materials in the economy – 'chemical engineering outside the pipe' (***tce*** 793, p21-22). A completely closed-loop zero-waste economy is, of course, thermodynamically impossible. However, a very simple (and simplified) example (see Figure 1) shows how elementary material balances can yield useful conclusions, in this case that serious reductions in energy use, far outweighing potential savings from improving the energy efficiency of industrial processes, can be realised by focussing on product design and use. The focus should be on design to reduce embodied materials; on using goods more intensively (eg car-pooling); on extending service lives and repairing or upgrading used products; and on designing products to be dismantled and the components re-used or, failing re-use, so that the materials can be separated and recycled.

The implications of extending product and component life have been explored in detail by the Product Life Institute's Walter Stahel in his book, 'The Performance Economy,' he suggests the maxim:

Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured.

Stahel, amongst others, has gone further to explore how the shift from disposable products to service delivery could lead to restructuring of a post-industrial economy. His simple maxim implies a major shift in economic activity: energy use would to a large extent be substituted by labour, mainly skilled labour, as re-engineering substitutes for primary material demand. Activities which are labour- rather than capital-intensive are less subject to the economies of scale which characterise the chemical and material industries. Thus Stahel's concept of the performance economy also embraces more localisation of economic activity.

foresighting and back-casting

While it is possible to envisage an economy with high material efficiency, the path to get there is less obvious. Extending product life represents a reversal of current trends; it requires behavioural change even more than changes in technology or product design. For many product groups, ranging from manufactured products like mobile telephones to clothing, service life is commonly limited by fashion rather than obsolescence or loss of functionality. As a specific example, the quantities of used clothing in the municipal waste stream have risen markedly in recent years, a trend which the UK's House of Commons Science and Technology Committee has dubbed 'the Primark effect.'

Reversing the current trend will require a combination of economic pressures and fashion. Some economic pressure is starting to come from the increasing cost and scarcity of critical materials such as the rare earth elements (REEs) (see ***tce*** 834 p33–35), heightened by China's limitations on exports of REEs. Manufacturers of products dependent on scarce elements have an increasing incentive to recover materials when their products reach the end of their service lives. This goes beyond the approach of mandating return or 'take-back' of used products, embodied in European directives such as those covering Waste Electrical and Electronic Equipment (WEEE) and End-of-Life Vehicles (ELVs), introduced at a time when economic pressures encouraging

Clift will explore what sustainability means to chemical engineers at:
IChemE's Sustainability Subject Group AGM
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take-back were missing. Increasing material scarcity will drive the move towards providing products on a lease or sale-and-return basis, moving towards one of the holy grails of industrial ecology: providing services rather than selling products.

Free-market economists argue that resource pricing via "the market" must be the driver or else the shift in business models will not succeed. Those who are less convinced of the virtue of a free market, maybe even thinking that a globalised market is one of the main processes which has brought the human economy into conflict with the environment, point out that one of the things governments can do is intervene in the market, most obviously by fiscal measures – ie taxation. The current approach, not just in the UK, is to tax labour rather than use of non-renewable resources, representing economic pressure in diametrically the wrong direction. Measures like the European Emission Trading System (ETS) represent hesitant moves towards taxing resources (in this case, the carrying capacity of the atmosphere and biosphere) and have arguably been too weak to have any serious effect in driving restructuring. An area of current debate among economists is ecological tax reform – shifting the tax base to resource use and environmental impact rather than labour. Such measures are generally opposed by established industries but need not be politically unthinkable if it is made clear that the changes should be revenue-neutral and not increase total tax revenues.

Where would this leave developing economies? From a global perspective, everybody would benefit if they developed in ways which embed material efficiency. Closed-loop material use along with industrial symbiosis – co-locating or connecting industries so that a waste or co-product from one becomes an input to another – are established bases for planning development in, for example, China and South Korea. Economic development based on exploiting primary resources will be helped if greater value is attached to those resources, but only if the added value accrues to the developing economy rather than a multinational developer; this implies further questions about the role of a globalised market.

A more closed-loop economy is a necessary part of sustainability but will need both political will and changes in popular fashion. **tce**

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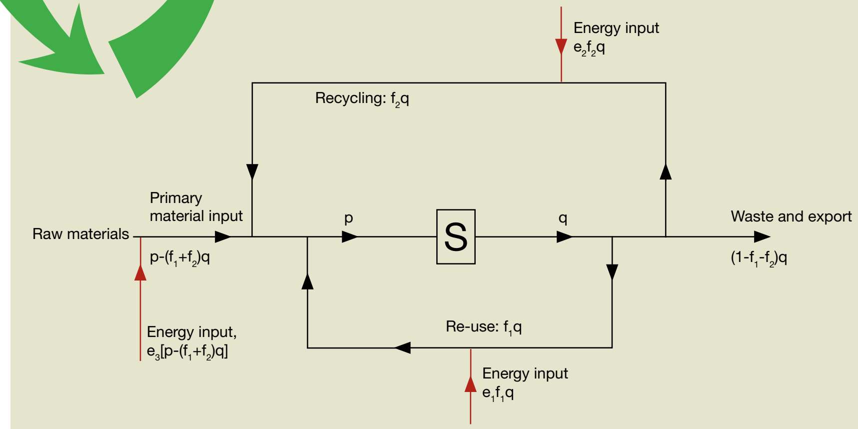
product life extension, re-use and recycling



e_1	Energy input per tonne of material re-use
e_2	Energy input per tonne of material recycled
e_3	Energy input per tonne of primary material
f_1	Fraction of post-use material recovered and re-used
f_2	Fraction of post-use material recovered and recycled
p	Annual flow of material entering use
q	Annual flow of post-use waste. (Note: for a mature sector, $q \approx p$)

Figure 1 shows a simple model to estimate the effects on energy use of changing the service lives of products and the proportion of products recovered after use and either re-used (ie put back into use without major reprocessing) or recycled (ie reprocessed). Usually, the energy required per tonne or unit for re-use (e_1) is much lower than for recycling (e_2); as a routine example, cleaning and refilling a glass or plastic bottle requires much less energy than reforming a new bottle from recycled material. Re-use includes re-engineering a complex product to incorporate used components. Recycling processes which involve phase change are associated with high values for e_2, so that cold-forming should be favoured. Even so, the energy for recycling (e_2) can often be much smaller than that required for producing the primary material (e_3); an extreme case is aluminium for which e_2 is around 5% of e_3, and recycling also avoids the other impacts associated with primary aluminium production including 'red mud' *(see **tce** 834/5 p28-29)*. Process scrap is treated as part of the production process and is therefore not shown. For a mature economy, the stock-in-use, S, is often roughly constant over time so that input and post-use waste flows are equal (ie p = q). The annual energy used to support the stock S is then, from Figure 1,

$$[e_1f_1 + e_2f_2 + e_3(1 - f_1 - f_2)]\ p$$

neglecting any energy input to waste management, which is usually small by comparison with e_1, e_2 or e_3. The flows p and q are determined by the mean service life, T, of the product group in question:

$$p = S / T$$

From these equations, the priority order of the options for reducing energy use are, for most product groups:

a) Extend service life, T, to reduce p;

b) Increase the proportion of post-use product re-used, f_1;

c) Increase the proportion of post-use product recycled, f_2;

d) Reduce the energy required for recycling, e_2;

e) Reduce the energy required for re-use, e_1;

f) Reduce the energy required for primary material production, e_3.