WHO GETS THE CREDIT?

The interpretation and misinterpretation of the results of LCA's applied to open loop recycling on polymer systems

The problem

Open loop recycling occurs when waste material from one production-and-use system is recovered, processed and fed to a second unrelated production-and-use system where it displaces material that would otherwise have to be derived from virgin sources.

Figure 1 shows an example of open-loop recycling in which post-consumer PET bottles are recovered, processed and sent to the production of fibre.

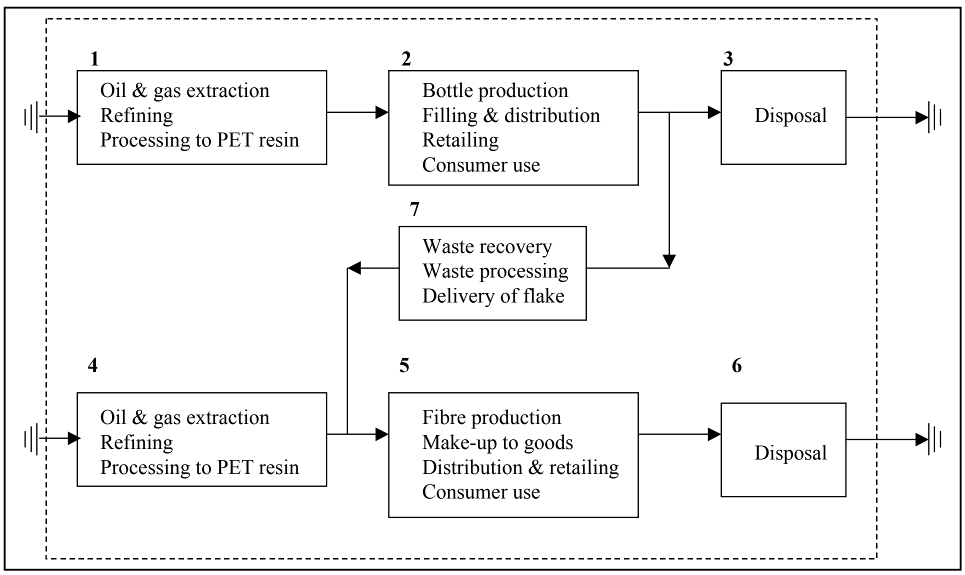

Figure 1. Open loop recycling from PET bottle production and use to PET fibre production and use. The overall system boundary is shown by the broken line. All inputs are derived directly from the earth and all outputs are sent back to the earth.

The important feature of this recycling system is that it contains sub-systems that could be designed to stand-alone. That is, operations 1, 2 and 3 represent the PET bottle system with no recycling. Operations 4, 5 and 6 represent the PET fibre system. It is hoped that, as a result of linking these two sub-systems with the recycling operation, there will be an overall decrease in the demand for energy and raw materials and a decrease in the emissions of solid, liquid and gaseous wastes.

The overall system contains two distinct and unrelated products: PET bottles and PET fibre. The question that is frequently asked is '*How are the* *benefits of introducing recycling partitioned between the PET bottles and the PET fibre?'*

The science

LCA is concerned with the behaviour of industrial systems. (Note in this context, the consumer is regarded as an industrial operation). Thus the LCA is concerned with evaluating the performance of three separate systems as shown in Figure 2, 3 and 4.

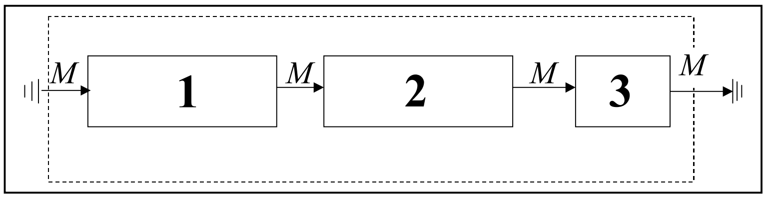

Figure 2. Simple linear system for the production of PET bottles from virgin raw materials. The operations correspond to operations 1, 2 and 3 in Figure 1.

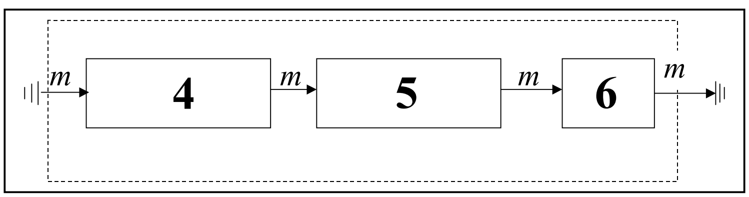

Figure 3. Simple linear system for the production of PET fibre from virgin raw materials. The operations correspond to operations 4, 5 and 6 in Figure 1.

Figure 2 shows the simple sequence of operations that would be needed to produce PET bottles from virgin raw materials. The operations 1, 2 and 3 correspond to those shown in Figure 1.

For any environmental parameter, P, assume that the values per unit throughput are P_1 for operation 1, P_2 for operation 2 and P_3 for operation 3. Further assume that the mass of material processed is M and that there are no losses in the system. The aggregated value of the parameter for the system shown in Figure 2 will be P', where

$$P' = M(P_1 + P_2 + P_3)$$

Note that this corresponds to a mass M of bottles passing through the consumer (operation 2).

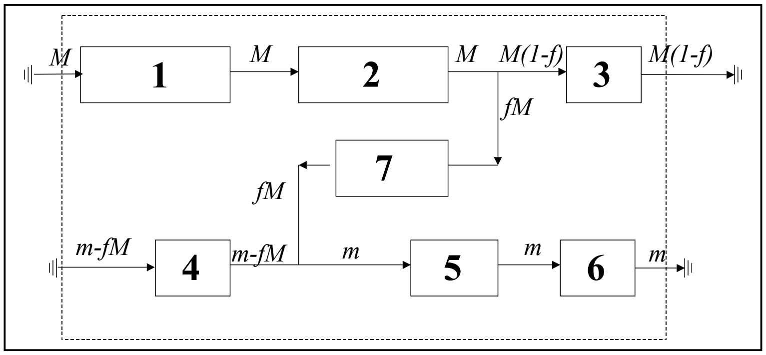

Figure 4. Open loop recycling system for PET bottles and PET fibre. The operation numbers correspond to those in Figure 1. See text for further explanation.

In the same way, writing P_4, P_5 and P_6 as the value of this same environmental parameter per unit throughput for operation 4, 5 and 6 in Figure 3, the aggregated value of this parameter for the system of Figure 3 is P'' given by:

$$P'' = m(P_4 + P_5 + P_6)$$

and this corresponds to a mass m of fibre passing through the consumer (operation 5).

Figure 4 shows the effect of recycling a fraction f of the PET bottle mass stream into the fibre stream. The masses have been adjusted so that a mass M of bottles passes the consumer and a mass m of fibre passes the consumer. For environmental parameter P, using the same procedure as before, the aggregated value for the system of Figure 4 is P''' where

$$P''' = MP_1 + MP_2 + M(1\text{-}f)P_3 + (m\text{-}fM)P_4 + mP_5 + mP_6 + fMP_7$$

Rearranging the terms gives:

$$P''' = M(P_1 + P_2 + P_3) + m(P_4 + P_5 + P_6) + fM(P_7 - P_3 - P_4)$$

$$= P' + P'' + fM(P_7 - P_3 - P_4)$$

If there is an improvement resulting from the introduction of recycling, then the parameter of interest is ΔP given by

ΔP = initial state with no recycling - final state with recycling

or

$$\Delta P = P' + P'' - P'''$$

and from the earlier equations

$$\Delta P = fM(P_3 + P_4 - P_7)$$

Provided that P_7 is less than the sum ($P_3 + P_4$) there will be an improvement in parameter P as a result of introducing recycling.

This indicates that the benefits, if any, arise from a reduction is the disposal operation in the PET bottle system and a reduction in the demand for virgin PET for the production of fibre. These changes are offset, in part, by the increasing value of P arising from the introduction of a new operation - the recycling operation.[1]

Why should there be a problem?

LCA's are concerned with descriptions of *systems* not *products*. The essential characteristic of a system is that it performs some *function* and in most industrial systems the function is generally to provide some service for the consumer.

In systems where there is only a single product passing through the consumer's hands, it is common practice to associate the performance of the system with the product. However, it is important to recognise that this is simply a matter of convenience and does not alter the fact that the system description refers to the system and not the product.

An over-emphasis on products leads to many unnecessary problems.

For example, there are some systems where there is no material product. Transport systems and communication systems have both been successfully analysed using LCA's yet in both instances there is no material product involved.

Furthermore, there are many instances, especially in packaging, where the product that is identified is unrelated to the function for which the system is set up. For example, in the PET bottle system, the function of the system is to deliver beer or carbonated soft drinks and the product, as far as the consumer is concerned, is the beer or the soft drink. To the consumer, the PET bottle is incidental.

For the open-loop recycling system, the systems approach adopted by an LCA analysis is capable of showing whether there is a reduction in any environmental parameter when recycling is introduced - as the simplified analysis earlier shows. An LCA is not and never has been concerned with products.[2] Thus in open-loop recycling the LCA examines the efficiency of the recycling system but it was never designed to provide information of products.

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[1] The above analysis assumes no losses in the materials processing operations. In practice this is unrealistic but if materials losses are included, the algebra becomes more complex but the final result is still of the same general form as in the loss-free situation and the conclusions are the same.

[2] The introduction of the term *product system* in the ISO work has only magnified the confusion.

The question of who gets the credit in an open-loop system is not new and has been around for the last 25 years. Initially, the question was posed by companies seeking some commercial advantage. Thus, in the PET example, the operators of the bottle system wanted to claim that they had improved because not only had they reduced their solid waste but they were also supplying material to a second production process. Equally, the fibre producers wanted to claim the benefit because they were using someone else's waste. Note that both arguments are product based, not system based.

THERE IS NO SCIENTIFIC WAY OF PARTITIONING THE CHANGE IN ANY PARAMETER IN AN OPEN-LOOP SYSTEM BETWEEN THE TWO PRODUCT FLOWS.

Does ISO 14041 help?

There have been some suggestions that ISO14041 provides a means of partitioning the benefits of open-loop recycling between the two product flows. This is completely wrong. ISO14041 is concerned with setting up the unit processes in inventory calculations. It is therefore interested in partitioning the characteristics of a unit process when there are multiple products leaving the system. This has nothing to do with the *interpretation* of the results of an LCI, which is the problem raised by the open loop interpretation. In the life-cycle system there are no products leaving the system - only wastes.

Partitioning by making assumptions

The only way in which the changes in the open loop system can be partitioned between the two product flows is by making some assumptions. It does not matter how much pseudo-science is invoked to justify such assumptions, the fact remains that they *are* assumptions. Consequently any conclusions that are drawn from a partition based on assumptions or any decisions that are made as a result of a partition based on assumptions are themselves subject to the same assumptions.

In the PET example, it is possible to split the changes equally between bottles and fibres. This is an arbitrary assignment and must be recognised as such; there is no logical argument that can lead to such a procedure. Similarly, procedures that assign all benefits to bottles or, conversely, to fibres, are equally arbitrary.

How to move forward?

Fact: LCA's are concerned with systems.

Fact: An LCA can demonstrate whether the introduction of open-loop recycling will produce any environmental benefit overall.

Fact: LCA's are not concerned with products.

Fact: Industrial systems are set up to provide some benefit for the consumer.

In the PET open-loop recycling case, the overall system exhibits two different functions and achieves this by providing two distinct products for use by the consumer: bottles for use in liquid packaging and fibres for use in clothing or other textile goods. From a consumer's viewpoint, the factor of importance is the quantity of PET passing through their hands since both of the functions exhibited by the system are related to the mass of polymer. It is therefore arguable that the overall characteristics should be partitioned on the basis of the mass of PET passing through the consumers' hands. This is still an arbitrary assumption but it does have, at least, the merit of some limited physical justification.

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2 September, 2001