Greener Manufacturing, Maintenance and Disposal – towards the ACARE targets.

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Abstract

This paper looks at how the aerospace industry can achieve the ACARE goal of greener manufacturing, maintenance and disposal. It looks further than merely reducing waste and eliminating hazardous materials and processes and suggests that the organisational structure of the industry will play an important role in facilitating a move towards such a goal. Greater co-operation or integration within the industry at all stages of the product life cycle chain is a fundamental requirement as individual companies run a risk of increasing the total environmental burdens if they concentrate solely on reducing their own impacts without considering the effect a change they make may have on other companies. The use of comprehensive environmental supply chain management systems and end of life plans can smooth the implementation of extended product responsibility and accelerate the benefits of greener manufacturing, maintenance and disposal.

Abbreviations

ACARE	Advisory Council for Aeronautics Research in Europe
DfE	Design for Environment
EOL	End of Life
EPR	Extended Product Responsibility
IPPC	Integrated Pollution and Prevention Control
LCA	Life Cycle Analysis
LTO	Landing and Take-off
MMD	Manufacture, Maintenance and Disposal
NOx	Oxides of Nitrogen

VOC Volatile organic compounds

1. Introduction

At the Paris Airshow in 2001, the aerospace industry launched the Council for Aeronautics Research in Europe (ACARE) and initiated a challenging set of targets for the industry to achieve by 2020. One of these targets was greener Manufacture, Maintenance and Disposal (MMD). Whilst the aviation industry has continuously improved its performance in operation through reduced fuel consumption, NOx emissions and noise, this was the first time that the impacts resulting from the other stages in a product life cycle (see figure 1) have been specifically targeted. The ACARE agenda for greener MMD has specified minimising the use of resources, reducing the use of harmful emissions to land, air and water and reducing the hazards associated with materials and processes. To reach this goal, they have acknowledged that the development of alternative processes with low or zero emissions will be required, and that a life cycle approach to improving environmental performance during all stages of the product life must be employed.

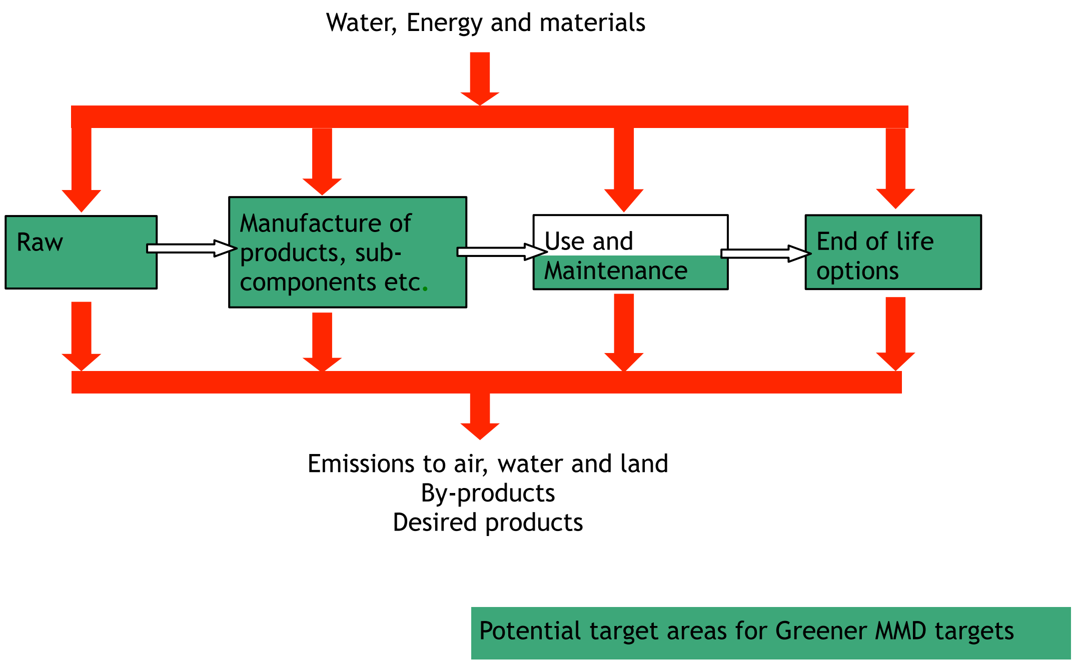

Figure 1: Simple linear product life cycle

The aviation industry, along with perhaps rail and sea transport, is subject to a unique set of design and operating constraints. The products are designed for long life[1], which means, most notably in case of propulsion devices, that the use stage of the product life incurs the greatest environmental impact. Until now, this is where most of the effort for reduction has been concentrated. In addition, the products are technically mature and complex, and are operated in a situation where safety is the over-riding issue. Aviation also has the additional constraint of weight sensitivity to safety and performance factors. This prevents ‘safety by overdesign’, an approach which is used for example in construction. It is thus a considerable challenge to reduce the total environmental impact resulting from aerospace products.

Aviation is a tightly controlled industry: strict regulation on the use stage of the product life cycle exist controlling noise and emissions through the landing and take-off cycle (LTO), and recently, there have been discussions on how to regulate emissions during cruise to reduce the impact on climate change. National and international environmental legislation banning hazardous materials have forced the removal of more dangerous materials from the product and tighter waste management regulation has reduced the impacts from inappropriate waste disposal. Integrated Pollution and Prevention Control (IPPC) legislation has ensured that manufacturing facilities do not release hazardous emissions to land, air or water. These existing regulations, along with a shift to life cycle based thinking have the potential to significantly reduce the environmental impact from aviation.

2. Methodology

There are three basic steps to accomplish greener MMD: the identification of what impacts occur and where they occur in the life cycle, the evaluation of alternative solutions, and the implementation of the best solutions available. These three stages are common whether the item under consideration is a simple nut and bolt, or a complex multi-component product.

[1] Aircraft and engines can have a life of between 45 and 65 years, from initial product concept to the removal from service of the last product. Engines and airframes are designed to provide service for at least 30 years.

Identification

The most comprehensive tool available for accurately identifying what environmental impacts occur at what stages of the life cycle is Life Cycle Analysis (LCA). In simple terms, this process lists all inputs to and outputs from the life cycle under investigation and assigns an environmental impact to those inputs and outputs. It therefore identifies the greatest impacts and where they occur during the life cycle. It is, however, dependant on using accurate data which can be difficult when the product life cycle encompasses many suppliers. In addition, LCA is extremely expensive and time consuming to complete and, as a result, various streamlined options have been developed and used. However, these can inadvertently miss out environmental concerns which might have a considerable impact on potential solutions.

Evaluation

Once the greatest impacts have been identified, it is then necessary to determine which impacts to tackle. A number of factors can influence the prioritisation process; legislation (current or expected), company targets, voluntary agreements, local or national pressures, available technology etc. Normally, a number of potential solutions would be suggested and the LCA study would be repeated for each of them to ensure that the proposed solution reduced the total burdens of the product rather than simply reducing the burdens for one particular stage but increasing the burdens elsewhere in the life cycle. An example of this might be changing to a composite material which gives greater manufacturing flexibility for a complex shape. A reduction of energy consumption during material and component manufacture may be experienced; however, the impact on disposal will be higher, as at the current time, there are very few secondary uses for composite materials and few disposal options other than landfill.

Implementation

This stage takes the best solution from the evaluation stage, puts it into practice and then starts the process again with another LCA study to evaluate where and what impacts occur from the improved life cycle. It is important to measure the actual benefits and impacts as these may be different from those estimated during the evaluation stage. More likely for large complex products, as LCA process is expensive, a major study would be carried out and used as a benchmark for a number of years and against which proposed modifications would be evaluated. The comprehensive LCA study would only repeated when the original life cycle was considered to be significantly outdated. An alternative driver for repeating the full LCA study could also be changes in legislation or acceptable business practices, which render the original study and conclusions obsolete. For example, the expected increase in disposal costs for materials that are subsequently classed as hazardous wastes as a result of their potential to contaminate land, could effectively eliminate or severely reduce their suitability for use.

3. Barriers to achieving greener MMD

The above approach is extremely effective for simple products with a short life span, but the scale of benefits which may be achieved from the application of the above strategy to a complex product are constrained by a number of barriers.

Length of product life

Environmental issues can change a great deal within a product life time which may last between forty-five and sixty-five years; new legislation passed, new environmental concerns discovered, increasing social pressures etc. Indeed, since the beginning of the industrial revolution there have been a number of environmental threats each considered at the time to be a potential threat to the survival of the human species. In the last thirty-five years alone, there have been environmental concerns such as ozone depletion (leading to the Montreal Protocol) which led to the banning of materials such as 1.1.1 Trichloroethane (Genclean), commonly used as a cleaning/degreasing agent, acid rain from coal fired power stations which was a factor in changing the fuel for electricity production, and smog, a concern especially around airports where NOx and VOC can interact to produce toxic ground level ozone. The current big issue is, of course, global climate change. All these environmental concerns have influenced local, regional or global communities and have been felt, to a lesser or greater extent, by designers in the transport industry. Identifying what may be the next ‘issue’ to incorporate into the design of long-lifed products can be a difficult task.

Technical maturity

Aerospace is a cutting edge industry, and the products involved have been developed over many years, refined and improved at a steady incremental pace. Since the product has been developed over a significant time frame there can be considerable inertia to overcome in moving from an established design or process to an alternative. This inertia is magnified for a safety oriented industry, where proving the pedigree of an alternative can be a time consuming and expensive process. Changes from an established design will only normally occur when a clear economic benefit can be identified, or when it is forced by legislation. One example of the effect of tighter environmental regulation has been the planned removal of hazardous materials such as asbestos or thoriated magnesium from components. The removal of these materials has in some cases forced a new design of the component to meet its performance requirements.

The aerospace product is mature and, as such does not offer as many opportunities for the radical innovation and development which characterised the beginning of the aviation industry. Where opportunities do exist, their attainment requires close co-operation between many different companies and technologies. This can be difficult to achieve.

The technical maturity of the product inversely influences the design freedom available of the product.

Design Freedom

In theory, when designing a product with environmental considerations in mind, (normally known as Design for Environment, DfE) environmental solutions can be developed on three distinct levels (1); cleaner processes, whereby the environmental effect is minimised, cleaner products, where the cause of the environmental effect is removed, and sustainable resource use, where the function of the product is considered and provided in the most sustainable manner. In practice, the levels are not so clearly defined. Electricity production is a good example of the application of the three levels of DfE. At the first stage, cleaner processes, minimising the environmental impact of coal fired power stations was achieved by adding clean up technology to the stacks to remove the sulphur dioxide before it was emitted to the atmosphere. The next level, cleaner product, electricity production shifted from sulphur rich coal as a feedstock to cleaner coal, gas and oil, thus reducing the need for clean up technology. The final level, sustainable resource use, electricity production is moving to ‘green’ renewable options, where there are minimal resource use issues or pollution concerns.

At the present time, the aviation industry primarily applies the first two levels of DfE, which are easier to initiate and are generally carried out within one company or sector of industry. Examples have included the removal of known hazardous materials and processes (as identified by legislation), introduction of material recycling systems, and closed loop processes. In addition, programmes to eliminate materials with high environmental risks but which as yet are not subject to legislation are identified and developed. Such programmes are often initiated by requests from final customers. One particularly successful application of DfE has been achieved as a result of the modular design of engines. This has provided opportunities to vastly improve the environmental performance of an engine by replacing one part with an alternative without requiring a full engine redesign. This modular replacement technique has been proven on the RB211-524G/H engine, where the incorporation of a low emission combustor has reduced NOx emissions and improved efficiency, creating the RB211-524G/H-T engine. A further advantage is that upgrades can be retro-fitted to earlier models.

Progression to the top level of DfE, sustainable design where significant environmental benefits can be realised, requires total design freedom - the ability to begin with a blank sheet of paper and consider the function of the product rather than the physical product itself. For example, in aviation, the function of an aeroplane could be defined as the transport of X passengers and Y tonnes of cargo a distance Z in A minutes. This definition then allows the consideration of different options of moving mechanisms dependant on the values of X,Y,Z and A. Within the closer remit of air travel, this might include evaluating new designs of engine and airframe shape, but at the extreme, this could include considering land based transport for low values of Z, or sea-based transport if A is not critical. Thus sustainable design for aviation becomes the wider issue of all forms transport, and requires interaction with many more stakeholders.

Spheres of Influence.

It is well recognised that the different stages of a product life cycle do not lie within the direct sphere of influence or control of the designer or one single company. For example, manufacturing may be subcontracted from the design company to a number of different organisations, and disposal may occur in another country many years after the initial sale of the product. Knowledge of the manufacturing processes or disposal options employed by these other organisations may be limited. Nevertheless, it should be the responsibility of the design authority to ensure that the best overall environmental solution is developed with all aspects of the life cycle considered at the design stage. This is the challenge facing aviation if it wishes to maximise the benefits from greener MMD.

4. A Potential Solution – Extended Product Responsibility (EPR)(2)

The design of the product ultimately influences every other stage of the product life and environmental risks need to be considered alongside other product attributes such as development time, time to market, performance, cost and reliability.

The term product stewardship, or extended product responsibility (EPR) has become widely recognised over the past few years. It is mentioned in the environmental management system standard, ISO 14001, and the green paper recently published by the European Union on Integrated Product Policy. However, there remains considerable confusion over its true definition; some have taken it to focus almost entirely on end of life issues, whilst others have embraced its effect at the front end of the product life through the reduction or removal of hazardous materials and processes.

The concept of EPR, that producers should be fully responsible for their products over life and disposal, opens many business opportunities. However, for some industries such as aviation, its application, whilst not impossible, raises some questions over current organisational structures and policies.

The effectiveness of DfE and hence greener MMD is directly proportional to the degree of influence or range of EPR held over the product life cycle by the design authority. It is possible to divide the product life cycle into two sections (see figure 2), the supply chain - all activities necessary upstream of the product assembly and sale, and the product chain - all activities after the product has been sold to its first customer, including all overhaul and maintenance requirements.

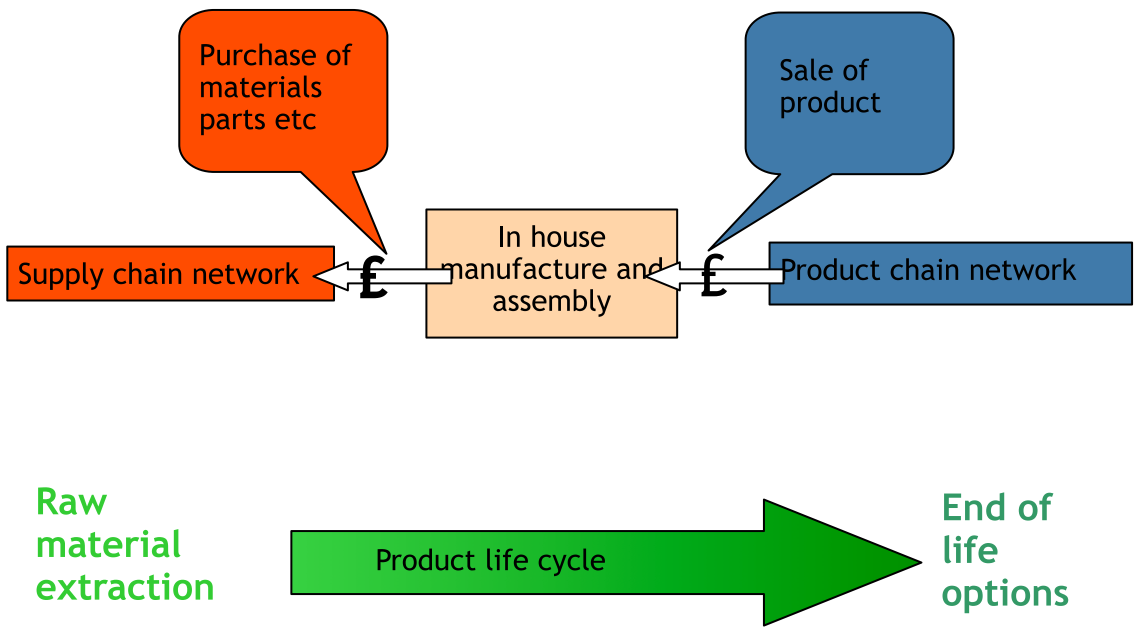

Figure 2: Supply and product chains

The range of EPR over the product and supply chains is a function of company policy, philosophy and product type. For example, if a company purchases a large quantity of a sub-component or material from a supplier to whom that contract forms a major part of their sales, then the purchasing company is in a position to exert considerable influence over the supplier. That influence could be used to obtain improved environmental performance in the production of components or materials. If on the other hand those sales only form a minor part of sales, the influence is reduced and the supplier is more likely to be predisposed to requirements from other parties in its customer base. The converse relationship, where there is only a single supplier for a particular component can also affect the overall environmental performance of the product. If the supplier chooses not to engage in activities to continuously improve its', and its' products, environmental performance, then there is little the consumer can do. If the particular component creates a large percentage of the total environmental impact, and the supplier cannot be enticed to reduce its impact, it may be necessary to investigate other means of provision such as setting up a joint venture company to supply the component.

The Supply Chain

Where design and manufacture is carried out in-house, control over the supply chain right back to materials supply can be relatively easily achieved. Environmental management systems such as ISO 14001 and EMAS play an important role in identifying, and subsequently managing, the environmental impact resulting from operations and, although in practice to a lesser extent, the product. In such circumstances, the 'polluter pays' principle is easy to enforce as the party responsible for the design of the product is also responsible for its manufacture.

It becomes more difficult to control the environmental impact of products when outsourcing and sub-contracting. This is becoming more common and has many benefits including allowing a business to focus on its core capabilities, and reducing capital expenditure on plant and equipment.

Environmental management systems encourage closer links with the supply chain, however, one of the major areas of concern with this is whilst environmental impact of processes tends to rest purely within a health, safety and environment type organisation, selection of suppliers rests within a procurement function. Procurement faces a number of conflicting requirements, but in general the over-riding issues for them are delivery, quality and cost. Until recently, incorporating environmental issues into supply chain decisions was relatively unknown and it is still the subject of much discussion. In addition, unless a trusting relationship exists, suppliers can be unwilling to divulge environmental information, on grounds of product confidentiality or concern that the information might somehow be used to drive down their prices.

Another potential issue for the supply chain is knowledge transfer. For non-critical components, there is a danger that specifications may not be reviewed as regularly or to the same detail as for critical parts or components. Thus a sub-contractor may be obliged to use outmoded or environmentally damaging processes, as determined by the specification, when better alternatives exist. Without a close relationship to the design authority this knowledge is unlikely to be transferred and the knowledge resource held by the sub-contractor is unlikely to be utilised to its full value. Taken to the extreme, the combination of infrequently reviewed specifications and/or overly specified product requirements and loose design authority/sub-contractor relationships can inhibit incorporation of cheaper, cleaner and more efficient manufacture of parts and components. Legislation can have the effect of raising the profile of non critical parts, for example the banning of hazardous materials or processes can force the redesign of components.

For critical components and parts, a closer relationship is more likely. Risk and revenue sharing partnerships, where the supplier takes on the risks for a percentage of the revenue generated by the product are becoming more common. For this type of supplier relationship environmental consideration of the component manufacture can be easy to control, provided such issues are considered when setting up the partnership. In addition, new manufacturing possibilities are more likely to be discussed early in the design process.

Effectively, increasing outsourcing and the number of sub-contractors can reduce the influence held over a supply chain. This can potentially lead to increased environmental impact unless it is supported by a rigorous environmental supply chain management system.

An alternative to enforcing supply chain management systems is to use market based mechanisms. For some materials, by charging the ‘true cost’ of components, a price which includes, for example, the cost of waste disposal and environmental clean up costs, it would be possible to encourage the purchase of more environmentally sound products. Integrated product policy is looking at this type of market mechanism (amongst many other options) and, whilst there remains some difficulty over the allocation of environmental costs across the supply chain, it is felt that this system has some merit. Market mechanisms, to some extent, remove the need for EPR in terms of influencing a supply chain to reduce environmental impact as, eventually, any company selling products with high environmental costs will be priced out of the market and thus business. However, this assumes that the market will provide sufficient incentive, which is not guaranteed, and may take some time to develop.

The Product Chain

The traditional system of selling a product to a customer, and at the same time handing over responsibility for that product is beginning to change. The paradigm shift from products to services allows a manufacturer to retain influence over the product life, and reap benefits not only at the end of life but at other critical stages. Returning a product to its manufacturer at the end of life (EOL) can help ensure that any residual value in the product, in terms of material resource, or reusable parts/components, is not lost. This is especially useful when the product contains rare materials as recycled or reclaimed material can reduce costs in manufacture.

An intermediate step between selling a product and a service exists for disposal - the creation of comprehensive EOL plans at the design stage. These plans should detail the materials in the product, any hazards to be considered during dismantling or disposal and suggested recycling/ reuse opportunities. They should also cover what happens to components replaced and repaired during maintenance. It is important to be realistic about what utility can be recovered, for example, simply stating that materials should be recycled when no facility or suitable process exists does not address the environmental issues which will arise at EOL. The success of EOL plans depends on the disposal company having a copy of the plans and being able to or willing to follow them. Implementation of the plan might be easy to enforce where there are only one or two owners of the product before final disposal, but for those products which may be sold on many times before final disposal it may be difficult to achieve.

Selling a service as opposed to a product follows the philosophy of EPR and increases the sphere of influence to end of life, but it also has some significant implications for product design, particularly for those products for which environmental impact is greatest during the use stage of the life cycle. For example, taking a simplified view in transport, selling a service implies selling the means by which people and/or goods can move from A to B. Thus a customer is only interested in a product when it is providing this function, and not when it is sitting idle. This also implies that maintenance and servicing would need to be minimised in order to maximise revenue from providing the service. In turn, minimised servicing implies a product with parts designed for long life, perhaps more robust (and possibly heavier), with greater safety factors[2]. For transport, where in general the majority of environmental impacts occur during the use stage, this could have a detrimental effect on total environmental impact (assuming the fuel used is fossil derived) as a heavier product will consume more fuel. For this type of product market, the benefits that could be accrued from improved end of life systems would be unlikely to outweigh the additional environmental costs from an increase in product weight. It is also important to weigh up the economic costs and benefits that could result from reduced maintenance schedules etc, against the increased environmental cost from the heavier product. Such issues need to be incorporated in the evaluation of costs and benefits resulting from a shift to selling services.

Greater control over products encourages and simplifies the implementation of industrial ecology, - maximising the value of a resource by using/reusing/recycling material in product chains. This is an underlying principle of 'factor 4' [(3)], a four fold increase in value from the use of a resource, in other words, a doubling of wealth but only using half the resources. The value of resource use, has been rising in recent years, and the latest figure to be suggested is a factor of 16.7 increase in resource value if we are to achieve a sustainable economy [(4)]. Aviation has already made significant contributions to improved resource efficiency, for example, aircraft now use less than half the fuel per passenger kilometre than 30 years ago. The challenge now is to extend this philosophy to MMD. If control is retained over a 'product' with multiple lives in various forms, the material choices made at the concept stage of the first product life need to facilitate the reuse of the product, or material. This minimises the selection and use of materials with a single function. Without this level of control, many products are designed for one use only, or whilst the materials may be suitable for reuse, the systems needed to realise the resource value do not exist.

5. Equalising the costs of greener MMD

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[2] It is possible that more robust designs may be over-engineered to reduce the risk of component failure through life with few scheduled services.

In the current business environment, a company is unlikely to pay for environmental modifications unless they are forced to by legislation, or there is a financial benefit from the investment. However, for some investments, the benefits do not occur at the same stage in the life cycle as the costs of implementation, and are thus gained by a second party. For example, if the design authority stipulates that a design should encourage disassembly and reuse of materials and components, the costs for that will be held by the manufacturer. The benefits in terms of materials or components to sell for reuse will be held by the disposal company. The allocation of costs and benefits are a major incentive or disincentive for the implementation of MMD, but with EPR the manufacturer would retain ownership of the product and any value from materials or components would return to the manufacturer, justifying the initial investment.

6. Conclusion

Extended product responsibility can provide an effective framework for reducing the environmental impact of products and it is essential if the full benefits of design for environment are to be realised, especially when applying the cleaner processes and cleaner products.

For the supply chain, EPR can only be achieved through the use of environmental management systems that enhance the importance of supply chain management or other equivalent mechanisms. Without this, little or no influence can be brought to bear on the often globally diverse supply chain. This can lead to situations where although a design may have incorporated environmental issues and concerns, the supplier is too far removed for effective management of those impacts.

In addition to increased supply chain management, market based (such as tax burdens) options or other incentives need to be designed to encourage improved environmental performance. Industry regulation could play a significant role in reaching the ACARE targets for greener MMD. As well as specifying performance requirements for the use stage, it could supply lists of ‘acceptable’ materials and processes for use in the industry – performance requirements for manufacture, maintenance and disposal, or take a more pro-active approach to the removal of materials use in aviation with known hazardous impacts during use or disposal. Regulation could also encourage and stimulate research into new processes and materials which meet these stricter environmental controls.

Mechanisms to extend responsibility into the product chain are needed. An intermediate step to improve downstream environmental impact is the creation of comprehensive EOL plans covering maintenance replacement/repair and final disposal of the product. A further step, EPR, encourages the shift from selling products to selling service, or function. Taken to the extreme, selling function could lead to a situation where material suppliers 'owned' the resource, leasing the function or value to a primary user. This would create financial incentives to minimise wastage and maximise resource recovery. A second benefit of this is that material suppliers would benefit more from materials with the potential for multiple product lives, and would place a premium on materials which did not. This could lead to a gradual phase out of single use materials, assuming reusable alternatives exist, and accelerate the implementation of industrial ecology.

For changes in either the supply or product chain to occur, information on materials, and their ability to be reused etc, is required. An understanding of the product impacts and where they occur during life is vital and the sustainable costs and benefits of end of life options need to be evaluated. This needs to include not just the technical feasibility, but also the 'hidden' costs of transport and capital expenditure.

Without EPR, greener MMD will fail to deliver the optimised product designs and the full benefits which are there to be realized.

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