WR1403: Business Waste Prevention Evidence Review

L2m5-5 – Automotive Sector

A report for
Defra

November 2011

This report has been prepared by:	Helmut Sengstschmid
Checked as a final copy by:	Katie Deegan
Reviewed by:	Nick Morley
Date:	22 October 2011
Contact:	helmut.sengstschmid@oakdenehollins.co.uk
File reference number:	WR1403-L2-m5-5-Automotive.docx

Context of Project WR1403

Waste prevention is at the top of the waste hierarchy. A major priority of the coalition government is to move towards a zero waste economy, and an important element of this will be to encourage and increase waste prevention. This review aims to map and collate the available evidence on business waste prevention. It will help inform the preparation of England's National Waste Prevention Programme as required under the revised EU Waste Framework Directive (2008).

The focus is on aspects of waste prevention that are influenced directly or indirectly by businesses - it complements a previous evidence review, WR1204, which focused on household waste prevention. The definition of the term 'waste prevention' used here is that in the revised Waste Framework Directive:

'Prevention' means measures taken before a substance, material or product has become waste, that reduce:

- *a) the quantity of waste, including through the re-use of products or the extension of the life span of products;*
- *a) the adverse impacts of the generated waste on the environment and human health; or*
- *b) the content of harmful substances in materials and products.*

Recycling activities or their promotion are outside the scope of this review.

Context of this module

This module is one of a number of Level 2 modules that contain analyses of Approaches, Interventions, Sector Issues and other aspects of the review. This module deals specifically with the aspect of waste prevention in the Automotive Sector.

A full map of the modular reporting structure can be found within **L1m2: Report Index**.

(Empty page)

Contents

Glossary

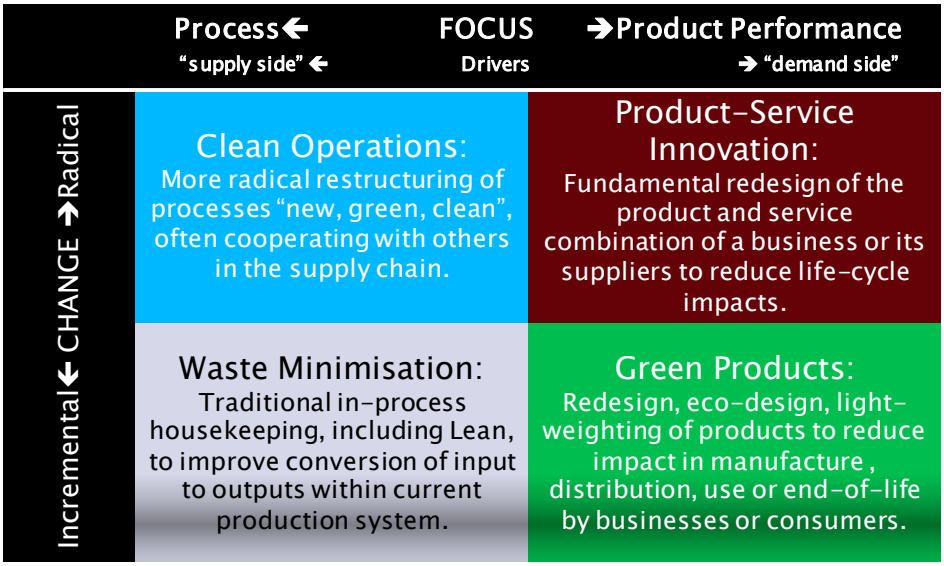
BIS	(Dept for) Business, Innovation and Skills	ONS	Office of National Statistics
CMS	Chemical Management Services	SCP	Sustainable Consumption and Production
CSR	Corporate Social Responsibility (report)	SME	small to medium sized enterprise (EU definition)
EPA	Environmental Protection Agency (US)	SMMT	Society of Motor Manufacturers and Traders
GHG	greenhouse gas	VOC	volatile organic compound
GM	General Motors	WFD	Waste Framework Directive

Units Conventional SI units and prefixes used throughout: {k, kilo, 1,000} {M, mega, 1,000,000} {G, giga, 10^9} {kg, kilogramme, unit mass} {t, metric tonne, 1,000 kg}

Language used in this report

This report has used a framework for evaluating both the actions a business takes to prevent waste (the Approaches), and the mechanisms that have catalysed the actions (the Interventions). The detailed description of Approaches and Interventions may be found within the respective modules **L2m2: Approaches** and **L2m4-0: Interventions Introduction**, but a brief reference outline to the Approaches is given here:

Positioning of approaches in response to business drivers including waste



Source: Oakdene Hollins/Brook Lyndhurst

1 The Automotive Sector in Context

This report concentrates largely on the core business of automotive manufacture by the main global brands. This largely excludes dealership and servicing as well as the upstream supply of components. However, these aspects have been touched upon in certain circumstances. For example, the introduction of product/service innovations (such as remanufacturing) requires the effort of dealerships and service outlets in retrieving vehicles from customers; and upstream in the servicing of vehicle components (motors, alternators, braking systems etc.) through reverse logistics chains from dealerships on behalf of the vehicle brands. These systems invariably employ large 'Tier 1' suppliers who are exposed to similar cost and CSR pressures to the assemblers. Beneath Tier 1 is a large cohort of diverse sub-suppliers, most likely serving local or regional assembly operations. These are not explicitly covered in this report.

Automotive manufacture also draws upon other services which may not all be mentioned in this report. However, the most obvious of these is Chemical Management Services (CMS) which provided chemicals, paints and other treatments as a service (rather than as bulk quantities to be managed by the automotive manufacturer itself) with incentives to minimise use and hence waste – especially hazardous waste; this service is considered.

The primary purpose in selecting this segment of the automotive sector is because it is generally believed to be advanced in the application of Lean Manufacturing practices, with strong cost and quality control. It may therefore reveal lessons for similarly structured, mature but technically innovative sectors.

In 2008 the automotive sector accounted for 10% of turnover in UK's manufacturing sector and contributed 2% of UK's gross value added.[a] The ONS estimated that waste generated in the sector totalled 1.65 million tonnes in 2006[b], which represents 0.5% of the total commercial and industrial waste generated in the UK. Approximately 10% of the sector's waste is hazardous, with the main share coming from chemicals.[c] Of the 90% non-hazardous waste the main components are metallic waste and 'mixed ordinary waste' as reported in Figure 1.

The manufacturing of vehicles is responsible for about 10% of energy consumption and CO_2 emissions during the whole life cycle of a vehicle (1). However, it is in manufacturing that the majority of solid waste (60-80%) is generated (2).

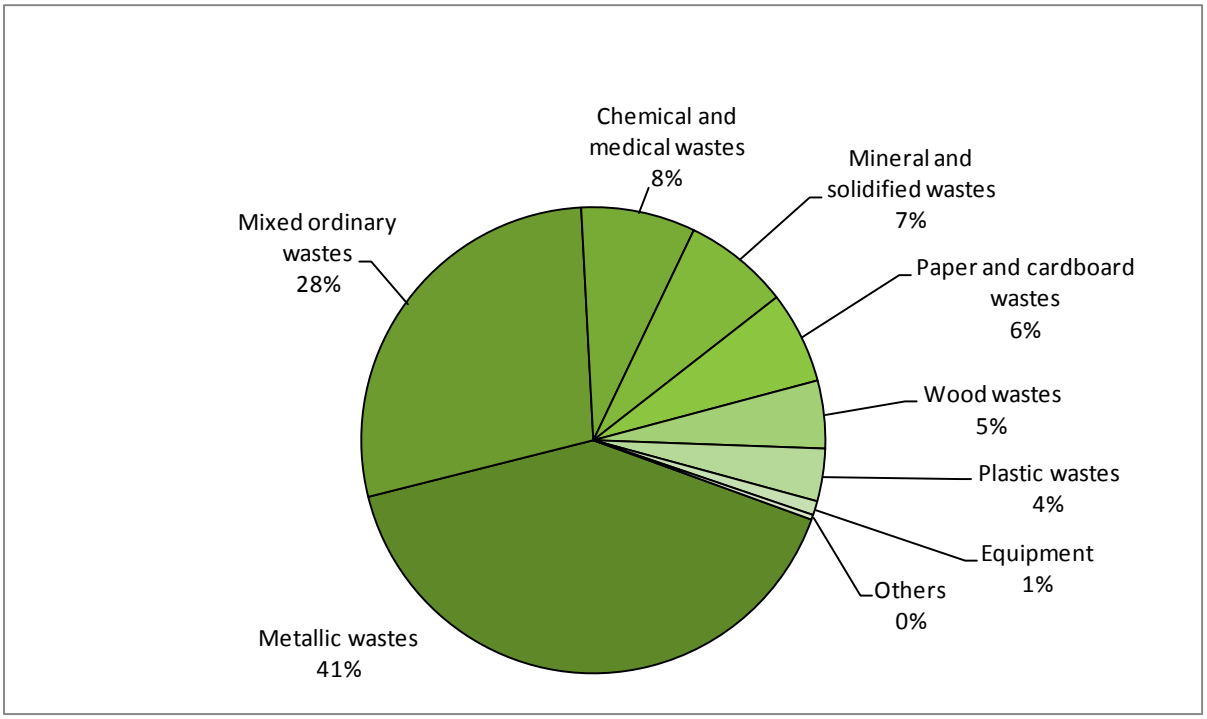
Even though improvements have been achieved by the automotive industry in achieving the 'Zero Waste to Landfill' goal (e.g. Toyota (3)), the evidence for similar progress in waste prevention is less clear. Individual companies disclose falling numbers for the amount of discarded waste (e.g. Figure 2) but data from UK's automotive industry indicates that waste generation is still increasing (Figure 3). This mixed result is surprising, as car manufacturing - due to its adoption of Lean Manufacturing techniques - has been at the forefront of waste prevention.

[a] ONS: Annual Business Inquiry 2008

[b] Estimates derived from Defra's 2006 submission to Eurostat

[c] Estimate derived from Eurostat 2008 data

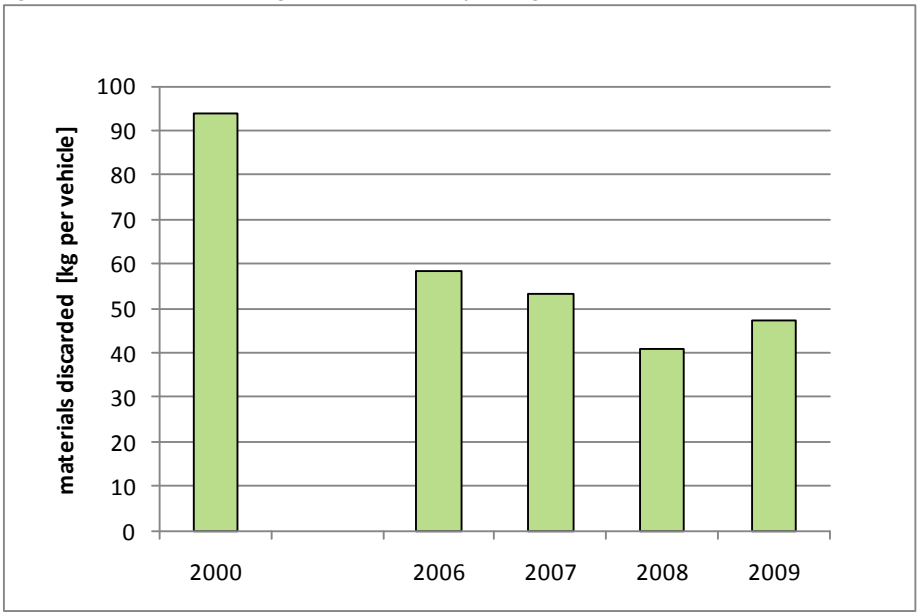
Figure 1: Types of waste in the automotive sector (UK)



Source: based on data from Eurostat 2008

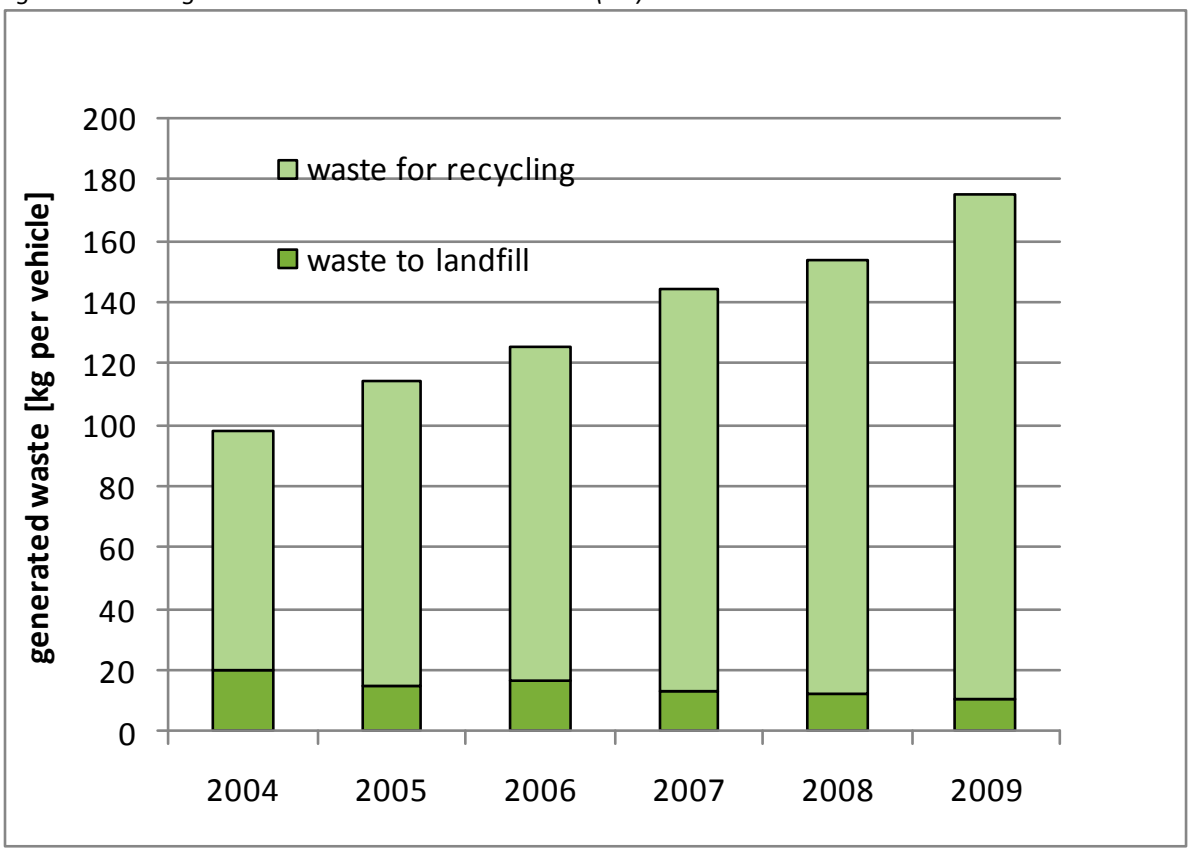
One explanation could be that even though some parts of automobiles are being light-weighted the overall weight of an automobile is ever increasing (4). Consequently, the material throughput is increasing leading to (all other factors being equal) an increased amount of waste. Another explanation may be the objective of Lean Manufacturing itself: while 'waste to landfill' has been in the minds of customers and regulatory bodies, and impressive results have been achieved, 'waste prevention' is less prominent. Indeed efforts to prevent waste may themselves have been considered 'waste' in Lean terms as they do not yet relate directly to customer (or regulator) satisfaction.

Figure 2: Trend in waste generation at Toyota (global)



Source: Oakdene Hollins based on data from Toyota's Sustainability report 2010 (5)

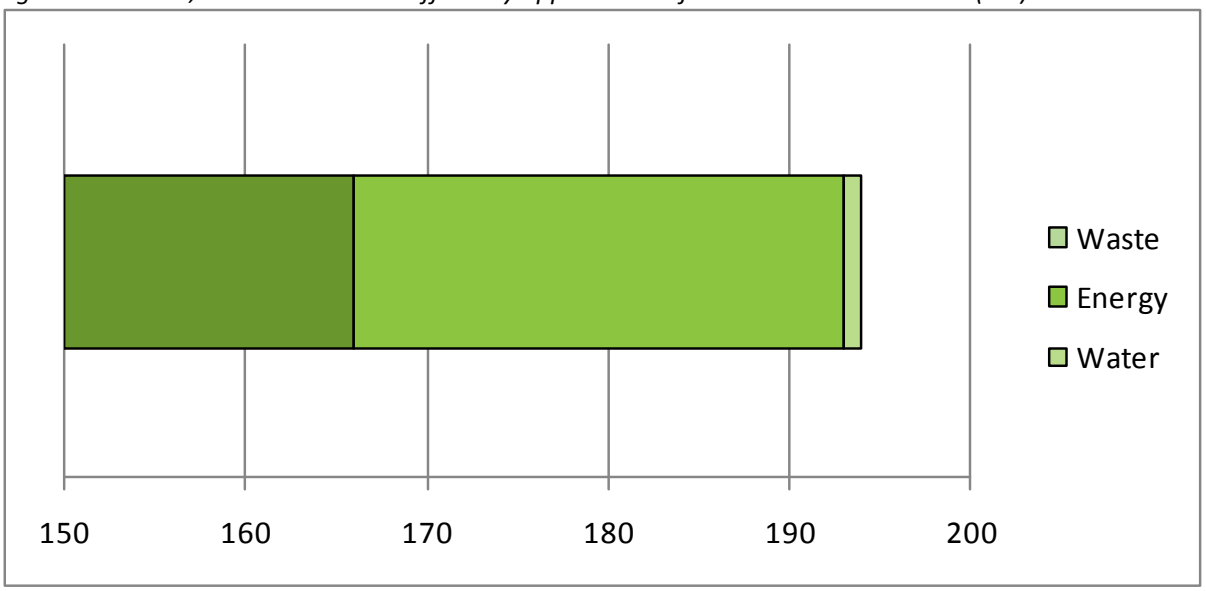
Figure 3: Waste generation in the automotive sector (UK)



Source: Oakdene Hollins based on data from SMMT (6)

The estimate of the no-cost, low-cost resource efficiency opportunities available in manufacturing of vehicles totalled £194m in 2007 (7). Of this opportunity, 86% is related to waste (Figure 4), with the largest savings identified by improving raw material yield.

Figure 4: No-cost, low-cost resource efficiency opportunities for the automotive sector (£m)



Source: Oakdene Hollins & Grant Thornton (7) *NB: Also includes industrial machinery statistics*

General interventions that have been highlighted to improve resource efficiency in the sector are (8):

- **Easy Wins:** Re-using rather than recycling pallets can achieve financial savings on site. Critically reviewing cleaning processes can save money; changing from single-use tissues (for machinery wipe down) to washable cotton wipes reduced costs from disposal to easily cover increased costs of the wipes and resulted in cost savings (the previous single use tissues were producing hazardous waste).
- **Waste:** By analysing additives to condenser units, and by changing the raw material specification, a company was able to convert the waste generated in its manufacturing process from hazardous to non-hazardous, significantly reducing costs of waste management.
- **Water:** Installing underground tanks for collection and treatment of rainwater from the roof of plant may allow re-use in the production process helping to conserve water and reduce costs. This could be in the form of settling tanks and reed bed filters so that water is of a higher standard of cleanliness for multiple re-use applications.

Besides manufacturing, wastes arise in repair and maintenance of vehicles. This often involves hazardous waste such as engine oils or chemicals involved in painting (stripping agents, solvents, paints). An additional source of waste is used tyres, which represent approx. 10 kg of waste per vehicle.

2 The Nature of the Evidence

There is significant evidence on waste prevention in the automotive sector. Both reports and case studies from various support initiatives to reduce waste and/or pollution have been found. The evidence of these reports is heavily oriented to successful activities with few reports of unsuccessful initiatives.

Reports from companies themselves form an important element of the evidence. Within these, the sustainability reports of leading manufacturers tend to focus on energy consumption, whereas waste is mainly reported in the context of diversion from landfill. A strong emphasis on achieving 'Zero Waste to Landfill' detracts from the more fundamental activity of waste prevention. These alternative agendas are reasons for the low number of reports and the lack of data on waste generation. However, the absence of evidence does not mean that waste prevention efforts are not occurring, as the identified examples show.

As an overture to a more detailed description of activities in this area, the case study of Box 1, relating to Japan's Top Runner scheme, describes one successful approach to driving performance improvement in whole classes of product – including Automotive. It reveals that there are some well-documented and perhaps transferable approaches in this area which appeal to the interests of both consumers and producers.

Box 1: Japan's Top Runner programme

Introduced in 1999 and administered by Japan's Agency for Natural Resources and Energy, the Top Runner programme aims to reduce energy consumption in the civil and transportation sectors by stimulating the continuous improvement in energy efficiency of products. Currently, 23 product classes are covered ranging from passenger vehicles and air conditioners to vending machines and even electric toilet seats. Rather than targeting retailers or end-users, Top Runner focuses on the supply-side, with manufacturers and importers required to meet minimum environmental standards. Appliances are tested, with the best performing model serving as a baseline for other manufacturers to meet or exceed. The next time officials set standards, the best available models will thus be even more efficient. In this way, standards are ratcheted up and energy conservation advanced through the replacement of machinery and equipment by consumers. Although focused on energy efficiency, the Top Runner scheme might equally well be applied to waste prevention.

Business Benefits

- The Top Runner scheme has improved many appliances and products. For instance, between 2001 and 2007, the energy efficiency of computers increased by 80.8% and magnetic disk units by 85.7%, surpassing expectations. These improvements will give Japanese manufacturers a competitive edge in the international marketplace.

Drivers

- Japan's scheme works because although businesses realise they will one day have to comply with new more stringent and legally-binding standard (the hidden 'stick'), innovation is driven primarily by the 'carrot' of competitive advantage. It should be noted, however, that the scheme has been criticised for rewarding incremental rather than transformative change.
- As part of a voluntary 'e-Mark' programme, certain products within the Top Runner scheme which meet the latest minimum requirements can display a label communicating this to retailers and consumers.

Key Elements for Success

- The Top Runner scheme is a non-confrontational approach to environmental protection. Although minimum standards once established become compulsory, the voluntary nature of progress towards better environmental performance harnesses businesses' own in-house expertise.
- Primary stakeholders are themselves involved in setting targets so awareness and commitment levels are high, while targets are not overly ambitious. Moreover, Japan has a culture of close co-operation between business and regulators.
- The scheme's iterative and flexible nature allows failures to be addressed and remedied.
- The 'free-rider effect' is an advantage because businesses already performing well at the start of a cycle become free-riders in needing to invest less additional effort during the subsequent compliance period.
- 'Name-and-shame' sanctions are effective deterrents in Japan.

Sources
http://www.asiaeec-col.eccj.or.jp/top_runner/index.html ;
http://www.enecho.meti.go.jp/policy/saveenergy/toprunner2010.03en.pdf
http://www.aid-ee.org/documents/018TopRunner-Japan.PDF

3 Evidence of Waste Prevention

3.1 Waste Minimisation

Based on the strong tradition of Lean Management and continuous improvement in the automotive sector, we expected to find a large body of evidence regarding waste prevention through improving the efficiency of processes. Surprisingly, apart from general reports about efforts to prevent the generation of waste (e.g. Toyota (9)), only a few examples could be identified:

- Improved quality of production to reduce defects and products not complying with specification: e.g. Aisin Europe Manufacturing UK Ltd (10), Delphi Automotive System (11).
- Improve paint-shop operations: e.g. the GM/Toyota joint venture NUMMI (12), DaimlerChrysler (13), KD Auto Body (14), General Motors (11), Leyland Trucks (9).

The lack of reports and studies might be explained by waste minimisation having been made part of the day-to-day running of the business (15); or that environmental improvements are often only a by-product of initiatives to increase throughput or to reduce inventory (11). Importantly, very few available case studies are from the UK, perhaps reflecting the subsidiarity of the UK automotive industry to interests elsewhere.

Waste audits in manufacturing companies will often find potential for waste prevention. Alloy Bodies, through the Enworks consultancy bank, undertook a waste survey to identify opportunities for improving waste management and reducing the costs associated with waste disposal. The company has since also improved its handling of raw materials resulting in less disposal. These on-going actions are expected to realise cost savings in the region of £24,000 annually (16) through material efficiency.

Another area of activities involves on-site recycling of solvents:

- 115 tonnes of waste prevented each year by reclaiming spent solvents by DaimlerChrysler (13)
- 80% of solvents recovered by installation of a distillation unit by KD Auto Body (14).

Table 1: Examples of waste prevention in the automotive sector by waste minimisation

Category	Supported	Description	Outcomes	Ref ID
Reduction in paint shop wastes	No	Improve paint shop operations to allow internal recycling of purge thinner (NUMMI, US)	$400,000/yr; 50% of purge thinner	(12)
Reduction in paint shop wastes	No	Improved 'first-time' quality and operational improvements in the paint shop (General Motors, UK)	270 t/yr of paint	(11)
Improve quality of processes to avoid scrap	No	Aisin Europe Manufacturing UK reduced metal scrap in door pressing operations.	£59,000/yr savings achieved	(10)
Reduced raw materials wastage	Enworks	Alloy Bodies used a waste survey to identify waste management cost savings which led to improved raw materials handling.	>£24,000/yr savings	(16)
Solvent recovery for in-process use	No	Daimler-Chrysler reclaimed spent solvents for internal recycling	115 t/yr	(13)
Solvent recovery for in-process use	No	KD Auto Body installed a distillation unit.	80% reduction of solvent waste	(14)
Reduction of oily wastes	Envirowise	B2 Automotive Components	100 t/yr of oily cutting wastes	(17)

Source: Collated by Oakdene Hollins/Brook Lyndhurst

3.2 Clean Operations

Many examples for improving process operations in the manufacturing of vehicles involve the introduction of reusable packaging of supplied materials: e.g. Leyland Trucks (9), Ford (18), Bosch (19), Toyota (20) (21), DaimlerChrysler (13) and the GM/Toyota joint venture NUMMI (12). Most of these initiatives are voluntary, while some are supported by publicly-funded waste reduction programmes. Even though packaging material like cardboard and wood amount to only to approximately 10% of the waste arisings (see Figure 1), significant cost savings can be achieved. Savings quoted include:

- $3m savings per year through reduction of packaging waste by NUMMI (US) (12).
- 23,000 tonnes of packaging waste saved by Ford (UK) through developing a system of returnable packaging together with suppliers and a packaging company (18).
- 3,000 tonnes of waste avoided annually by Toyota (US) through switching to returnable packaging for carpets (21).
- Similar initiatives are reported for Leyland Trucks (9) and Bosch (Wales) (22), though the amount of waste saved is not reported.

Another area of evidence stems from new technology in painting cars. It seems that these improvements are not primarily aimed at reduced waste, but at reducing emissions of volatile organic chemicals and to improve workplace hygiene. Such innovative technologies are employed both by manufacturers such as Leyland (9) and Toyota (23) and by repair shops such as KD Auto Body (14) and Rhode Island (24). Besides a reduction of cost, regulatory pressure is an importance motivation, especially for SMEs. Specific savings include:

- 68 tonnes of waste (55 tonnes of which hazardous) prevented annually by Trimac Transportation through switching from cleaning with methylene chloride to blasting with baking soda (25).
- Similar initiatives are reported for Leyland Trucks (9), KD Auto Body (14) and the sector of small car repair shops in the Rhode Island study (24), but without stating the amount of waste saved.

We have been unable to locate much evidence of large investments in new equipment by businesses involved in this sector, an exception being Tital (26). However, smaller changes are much more numerous such as changing minor raw materials to avoid hazardous waste (DENSO (16)). Two examples of innovative technologies are:

- 8 kg per item of milling tools saved by Tital (Germany) through substituting a milling process by an innovative new foundry operation (26).
- 600 tonnes of waste per year from spent purge solvents prevented by the introduction of the use of paint cartridges by Toyota (US) (23).

In the aftermarket[a] an interesting example is company Apollo, which changed its product strategy from exchanging damaged parts to repairing them (22). This was made possible by the close support of its main customer, an insurance company. A 42% reduction in waste generation was achieved.

In the use phase of vehicles, a widely reported issue is the use of oil by-pass filters. Studies have shown a notable reduction in the frequency of engine oil changes by using these filters (27) (28). An 80% reduction of engine oil use/waste by installation of by-pass filters was achieved by both the Idaho National Laboratory and the Department of Education in North Carolina.

[a] In the automotive sector, aftermarket refers to (sales in) the period after the manufacturer's or dealer's warranty has expired.

Table 2: Examples of waste prevention in the automotive sector by clean operations

Category	Supported	Description	Outcomes	Ref ID
Reusable packaging	No	'One-liner' outlining key features company etc. (NUMMI)	$3m annual savings	(12)
	No	Implement system of returnable packaging with suppliers (Ford)	23,000 t/yr packaging waste prevented	(18)
	Yes	Introducing reusable packaging for its carpets (Toyota)	3,000 t/yr packaging waste avoided	(21)
Reusable cleaners	No	Switched from single use to washable/reusable wipes (DENSO)	Reduced hazardous waste cost by £5k	(16)
Avoid hazardous process chemicals	Yes	Switching from cleaning with methylene chloride to blasting with baking soda (Trimac Transportation)	68 t/yr packaging waste saved	(25)
	No	Used liquid flux instead of using powder flux and purchased ready-coated flux materials (DENSO)	Reduced hazardous waste by 22% in first year.	(16)
New technology	Yes	Investing in a new innovative foundry process (Tital)	8 kg/item waste of milling tools prevented	(26)
	No	Introduction of paint cartridges to reduce purge solvent for switching colours (Toyota)	600 t/yr waste prevented	(23)
	No	New technology to allow repair of damaged car parts (Apollo)	A 42% reduction in waste generation	(22)
	Yes	Installation of oil bypass filters to reduce frequency of oil changes in commercial transport fleets	80% reduction of engine oil use	

Source: Collated by Oakdene Hollins/Brook Lyndhurst

3.3 Green Products

Product redesign plays a very important role in automotive manufacturing to improve energy efficiencies, yet very little evidence has been found for it being used for waste prevention[a]. On the contrary, a study described the failure of an EU-funded project (29) supporting development an IT tool to help designers to design-in waste prevention by improving the ability to re-use and to remanufacture, as well as recycling. However, the automotive industry lost its interest in this tool when it became clear that emerging shredder technology would be able to achieve the recycling rates as to comply with the End of Life Vehicle Directive. A further example of this approach is BMW's 'design for recycling'. Its aim is to enable easy removal of those parts that need to be removed to allow successful shredding and recycling (e.g. parts contaminated with fuel, oil). Even though this allows the achievement of a high recycling rate, it is not addressing waste prevention itself (30). In a similar fashion Mercedes describes the waste aspects of its 'Design for the Environment' mainly in terms of ensuring ease of recycling (e.g. by easy disassembly of thermoplastic bumpers), or of using recycled materials (31). Prevention of waste, e.g. by re-use and remanufacturing, is not presented prominently.

Light-weighting plays an important part in waste prevention in the food and retail sector by reducing the weight of non-essential parts of the final product, especially packaging. However, in the automotive sector the alleged purpose of light-weighting is not to lower material going to the scrap-yard, but to improve the energy efficiency of the car. The true picture is more complicated: One study (LIRECAR) found that light-weighting of cars does not lead to a significant improvement in the generation of waste over the whole life cycle of a vehicle (32). Even though the weight of components may have been reduced, the gains with respect to waste prevention at the product disposal stage are often compensated by increased waste at the production stage. Another study has shown that even though light-weighting may be applied to certain components of a car, the overall weight of cars continues to increase (4). This reveals the challenge of trading off various objectives – emissions, recyclability, waste in manufacture, as well as customer wants – presented to the modern vehicle manufacturer.

[a] The obvious extension is the background improvement in vehicle reliability, corrosion-proofedness and service interval extension, all major achievements, to the delight of customers.

Toyota in the US is an exception in revealing eco-design initiatives (23): To eliminate hazardous waste the material of the fuel tank was changed from metal to plastic which rendered the barium-containing corrosion inhibitor obsolete, resulting in 180 tonnes of hazardous waste being avoided annually. In another case waste prevention was achieved as a by-product of a change of design (21): By altering their truckboard from a design with a basic board and a liner to a design with a single composite board, Toyota managed to avoid all the packaging for the liners, thus halving the number of pallets being used.

Box 2: Toyota and ISO 14001

The automotive manufacturer Toyota has a strong presence in Europe with nine production facilities in the UK, France, Poland, Czech Republic, Russia, Turkey and Portugal representing a total investment of around €7bn. In 1996, Toyota Manufacturing UK (TMUK) became the first UK based car maker to gain ISO 14001 accreditation for its management processes, later asking suppliers to gain the certification by 2003. In 2000, TMUK's sites at Burnaston and Deeside were earmarked as 'model sustainable plants' in which methodologies for achieving optimal environmental performance would be piloted. TMUK set a goal of zero waste to landfill by 2005, tackling it in three stages: reducing waste volume, reusing or recycling unavoidable waste, and treating any waste that could not be re-used or recycled to reduce its environmental impact.

Business Benefits

- TMUK has achieved its target of zero waste to landfill and, more recently, zero waste to incineration.
- Between 1993 and 2007, TMUK cut waste from UK car production by 60% to around 10kg per car and reduced the release of hazardous volatile organic compounds by 70% to 20g/ m^2 of paint surface. However, whether these savings were directly correlated to the adoption of ISO 14001 is unclear. Greater efficiencies in water and electricity usage per vehicle have also been documented.
- Other benefits from implementing and maintaining an EMS may include marketing advantages by demonstrating to stakeholders that the company is committed to effective environmental management and reduced risk of international non-tariff trade barriers.

Drivers

- The EMS was implemented as part of Toyota's commitment to achieve zero waste to landfill. The car maker is generally regarded as setting benchmark standards in 'lean' manufacturing, in other words production processes in which waste and inefficiency are continuously driven towards minimal levels. Toyota Motor Europe's aim is to be 'green, clean and lean' and its long-term objective, as stated in its corporate 'Earth Charter' is production of the 'ultimate eco-car'.

Key Elements for Success

- Toyota is famous for its 'kaizen' philosophy of continuous improvement where new ideas are welcomed from anywhere within the global organisation. This approach works in synergy with ISO 14001 for which continuous environmental improvement is a key objective. New waste saving techniques are first proven at a local level within a single site and if effective the relevant procedures are then diffused to the rest of that particular location and then by degrees to the rest of the business.
- Through its environmental purchasing guidelines, Toyota used its power in the supply chain to influence business partners so that they make environmental protection a priority.
- Full commitment by top management to environmental protection is fundamental to the successful implementation of an EMS.
- Provision of skills training and awareness building is important. A valuable approach practised at the Burnaston plant was to take employees on 'eco tours' around parts of the factory they would not normally - see such as the waste management facility - which improved their understanding of waste.

Sources:
http://www.iema.net/readingroom/casestudies?filter=163%2C189&aid=584;
*http://blog.toyota.co.uk/behind-the-scenes-toyota-promotes-environmental-excellence-at-*the-*home-of-auris-hybrid;*
http://www.iso.org/iso/14001_decade_ims3_07.pdf
http://www.mrcmekong.org/envir_training_kit/English/Case%20Studies/PDF/CS19%20-%20Toyota%20Motor%20Vietnam.pdf

Table 3: Examples of waste prevention in the automotive sector by green products

Category	Supported	Description	Outcomes	Ref ID
Choice of materials	No	Change material of tank from metal to plastic to avoid need of corrosion inhibitors (Toyota)	Avoid 180 t/yr of hazardous waste	(23)
	No	Change material of truckboard from two components to composite to reduce number of individual parts and of packaging	Halving the number of pallets used	(21)
Hazardous substances	No	Voluntarily applying ban of mercury in Europe to US production (DaimlerChrysler)	Phase out of switches containing mercury	(33)
	No	Voluntarily applying principles regarding hazardous substance from cars to fork lift trucks (Toyota)	complete elimination of Pb, Cd, Hg, Cr(VI)	(34)

Source: Collated by Oakdene Hollins/Brook Lyndhurst

3.4 Product/Service Innovation

The examples of product/service innovation identified in the automotive sector focus on re-use and remanufacturing of used vehicles parts. One of the largest remanufacturers is Caterpillar (CAT) which has its European headquarter in Shrewsbury, UK (35). A wide range of components and products are taken back, cleaned and remanufactured to the same standards as original products. CAT's Annual Report states that 43,000 tonnes of material has been re-used by the global remanufacturing business (35).

Box 3: Remanufacturing by Caterpillar

Remanufacturing is defined as a series of manufacturing steps acting on an end-of-life part or product to return it to like-new or better performance, with warranty to match. Caterpillar (CAT), the world's largest maker of off-road vehicles, construction and mining equipment, is a high profile pioneer of remanufacturing. The company not only makes new products but also takes back old components, cleans and remanufactures them, and sells them again. By adopting this product/service innovation approach CAT has reinvented its business.

Business Benefits

- In 2005, CAT's global remanufacturing operation re-used 43,000 tonnes of core materials. Not only does this translate as a vast financial saving, but the emission of some 52 million tonnes of GHG was prevented. Wastes associated with raw material extraction were also substantially reduced.
- The demand for remanufactured products is huge; CAT sells them to large haulage fleet operators, the Ministry of Defence, train operators, mining and quarrying firms, farmers, construction companies and marine users.
- Not only does CAT remanufacture its own products but from its regional hubs – such as one in Shrewsbury, UK – the company also provides a remanufacturing service to other OEMs (original equipment manufacturers).

Drivers

- Customer pressure was a key driver. CAT first explored remanufacturing back in 1972 after US truck fleets operators demanded high quality, low cost replacement engines.

Key Elements for Success

- CAT is aware of the stigma attached to 'second hand' goods, so every remanufactured product or component goes through the same stringent quality test procedure as a new product does, and is given a warranty. In many cases, the products will be remanufactured on the same production lines as their new counterparts and often leave the plant in 'better than new' condition as every part is modified to include the latest design features.
- CAT maximises the flexibility in the type of components it can remanufacture by using patented processes, procedures and tools to dismantle, modify, and reassemble the products.

Another example is Achmea, which set up a system of using used parts for repairs in the Netherlands (36). The impetus for this organisation was business support, i.e. an EU-funded project to prove the feasibility of such a concept. 180-210 tonnes were saved annually by setting up a system to use used parts for car repairs (36).

Box 4: Achmea Parts Service and the RESPECT project

Damaged and end-of-life vehicles generate significant quantities of waste metal, plastic, rubber and glass of which a large proportion is hazardous shredder material sent to landfill. Through its LIFE Programme, the European Union in 2000 supported an innovative approach in the Netherlands to reusing automotive parts. At the time, all hire vehicles in the country were repaired with new parts with no system for managing the flow of used parts. Achmea Parts Service created a network of car dismantlers, body shops, car fleet managers and insurance companies. It promoted large scale re-use of used car parts through a new 'green insurance' scheme with lower premiums than regular policies: essentially, clients with the green policy have their car repaired with used parts. Achmea demonstrated that the system would be economically, ecologically and technically viable and that 80% of all car damage could be repaired with used parts without compromising quality standards.

Business Benefits

- Achmea successfully realised the large-scale re-use of second hand car components leading to a win-win situation, with significant environmental and economic benefits. By early 2002, some 75,000 green policies had been sold with 6,000 repairs performed with used parts. Emissions from painting were halved as used parts require fewer or no additional paint layers, while some 60 tonnes of material were saved in 2001 alone.
- However, the scheme suffers from the fact that parts suitable for newer vehicles – which represent the bulk of the lease market – are rarer. Therefore the green policy tends to be offered to customers with cars older than three years.

Drivers

- The cost and regulations associated with disposal of end-of-life vehicles in Europe was a key driver for some elements of the supply chain, while other parties benefited from reduced vehicle repair bills or insurance premiums.

Key Elements for Success

- Funding from the EU LIFE Programme was important at the outset.
- All parties involved in the project put much effort into the project's implementation. They demonstrated the viability of the concept of green repairing, created the required procedures and quality assurances, and worked hard at improving the professionalism of the dismantling industry. They also undertook wide scale dissemination activities.
- The information technology system developed for the project makes for effective and efficient communication between all parties in the scheme.

A more general example is the retreading of vehicle tyres: This technology has become an accepted practice for knowledgeable customers, with an estimated 50% of all replacements for tyres of commercial vehicles in Europe being retreaded (37). 1.6 million tyres were retreaded in UK in 1994, representing 50% of replacement tyres for commercial vehicles (37).

Table 4: Examples of waste prevention in the automotive sector by product/service innovation

Category	Supported	Description	Outcomes	Ref ID
Re-use	Yes	Implement network of repair shops to re-use used parts, including setting up of a 'green' car insurance scheme to provide incentives for customers.	180-210 tonnes of parts re-used per year	(36)
Re-manufacturing	No	Remanufacturing of parts and components by Caterpillar.	43 kt of material remanufactured per year	(35)
	No	Retreading of tyres	1.6m tons of tyres remanufactured in 1994	(37)

Source: Collated by Oakdene Hollins/Brook Lyndhurst

Waste reduction can also be achieved by outsourcing the management of the use of hazardous chemicals to third party agents. From the perspective of the business concerned, this is classed here as waste minimisation. From the perspective of the third party, it is a product/service innovation. In order to provide appropriate differentiation of such pioneering efforts, we describe one significant development in this area that has emerged in the UK in the last decade: Chemical Management Services or CMS.

CMS, as the name implies, involves a supplier of chemicals taking substantial responsibility for the specification, use, recovery and even re-use of those chemicals by their customer. This may be driven by actual or impending legislative pressures, but is typically sold as a financial opportunity for both parties, with performance incentives linked to a baseline consumption which reduces over time. CMS has made substantial inroads in heartland engineering and most notably in the automotive sector (it also appears in aerospace, electronics, food and drink and machine shops sectors) where the application of chemicals is not a 'core competence' and may safely be out-sourced to a third party without threat to operations. Typical chemical duties covered include water treatment, surface preparation and finishing, paint shop management and cutting fluid management.

We were unable to locate well quantified examples, but there are anecdotes of significant impacts in vehicle manufacturer paint shops in particular. According to CMS Forum's 2004 Industry Report, typical client savings are 6-10% per year, largely attributable to reduced chemical usage. Whilst absolute figures on hazardous waste are not available, this does provide a strong indicator of the potential, especially given that Europe and Asia are less cultural receptive to the concept than the US (38). As such, the CMS approach appears to address waste, hazard and legislative concerns through a commercial incentive and to mutual advantage.

3.5 Mixed Approaches and Tools

Two studies indicate that potential for waste prevention in the automotive sector is comparatively low. A study for BIS showed that very little material use reduction (only 36 tonnes per year per opportunity) is expected for the automotive industry (8). The investment required to achieve this is relatively high and payback relatively low (1.4 years). A study of resource efficiency improvements across more than ten sectors showed that opportunities in the automotive sector were far less than in the oil/petroleum, health or metal finishing sectors (15).

A key theme of automotive manufacturing is Lean Management. Waste prevention is built into Lean Management but 'waste' is understood as being much broader than environmental issues, focusing more on reducing process time and inventory than on reducing scrap and material waste (1). However, Lean is not incompatible with sustainability, as a study in the US (11) showed:

- Lean fosters a continual improvement culture which involves shop-floor employees and which is similar to existing voluntary environmental programs and initiatives.

- Even though Lean drivers – improvements in competitiveness by reducing capital and time intensity of production processes – are much stronger than savings from material use or disposal costs, environmental improvements may ride on the back of Lean changes leading to a win-win situation for business and environment.
- Lean tools provide an excellent platform for other environmental management systems (39), but also for life cycle assessments and eco-design, which can be further applied.

These findings should be tempered by the fact that Lean Management does not directly address waste prevention in manufacturing (11):

- Lean methods do not explicitly address solid and hazardous waste as targets for elimination. However, they are implicitly embedded in the Lean 'waste' types, and waste prevention in the sense of the WFD occurs as a welcome by-product of improvement initiatives.
- Lean methods have 'blind spots' with respect to environmental risk (e.g. substituting hazardous materials) and life-cycle impacts.
- Environmentally sensitive processes (e.g. painting, chemical treatments) are notoriously difficult to make Lean due to their inherent batch character and to regulatory restrictions.

On the whole Lean is recognised by environmental experts (39) and by the EPA (11) as a powerful tool to drive environmental improvement. A recent case study in the aerospace industry estimated resource efficiency improvements in the range of 30-70% could be achieved due to implementation of a Lean Management culture (40).

Unfortunately, as the main drivers for Lean initiatives are inventory reduction and improvements in throughput, most companies do not track or quantify their improvements regarding waste prevention, and there is comparatively little data available.

3.6 Hazard Reduction

A reduction in the amount of solvent waste generated in paint-shops is a good example of the industry's drive to reduce hazard. In addition to the cost savings afforded due to reduced disposal costs, a reduction of business liability is an important driver (14).

Examples based on green products (Section 3.3) include:

- Toyota: Complete elimination of lead, cadmium, mercury and chromium(VI) by voluntarily applying passenger car standards to fork lift trucks (34).
- Toyota: Changed material of tank from metal to plastic avoiding need of corrosion inhibitors saving 180 tonnes of hazardous waste annually (23).
- DaimlerChrysler: Phased out mercury-containing switches by voluntarily transcribing the EU ban to US plants (33).

Examples based on clean operations (Section 3.2) include:

- Trimac Transportation, an SME specialised in cleaning of tanks for the automotive industry: By switching to a blasting system with baking soda they managed to save 55 tonnes of hazardous waste per year (of which 24 tonnes toxic) (25).
- DENSO: By applying liquid flux to intricate areas of condenser units instead of using flux powder and by purchasing ready-coated flux material, the company reduced its hazardous waste generation by 22% in the first year (16).
- DENSO: The company changed from using single-use tissues required to wipe down machinery, to washable cotton wipes. Investigations showed that the purchase and disposal of tissue were more

expensive than purchasing and washing cotton rags. In the first year, the change resulted in a £5,000 reduction costs and hazardous waste generation (16).

- b2 Automotive Components: Reduction of oily wastes by 100 tonnes per year, saving £5,500 (17).
- Reduction of engine oil use of 80% by installation of oil by-pass filters to reduce the frequency of oil changes in commercial transport fleets (Idaho National Laboratory and the Department of Education in North Carolina) (27) (28).

Examples based on waste minimisation (Section 3.1) include:

- NUMMI: Reduction of purge thinner from 8.3 to 2.3 litres per vehicle (12).
- Toyota: Reduction of purge thinner by 600 tonnes per year through new technology; avoiding need for barium-containing chemicals through material change of fuel tanks (180 tonnes annually) (23).
- General Motors (GM): Overall Lean activities in its Saturn automotive manufacturing plant led to a drop in hazardous waste generation from 4.5 kg per car in 1992 down to 1.6 kg per car in 1996 (11).
- Daimler Chrysler: Total Chemical Management: 115 tonnes of solvents saved annually (13).
- KD Auto Body: 80% of solvents recovered by distillation (14).

Box 5: HazRed

Launched in 2004, the three-year HazRed project aimed to check the rise in hazardous waste generation across Europe. Funded through the EU LIFE Programme, the project sought to address hazardous arisings from small and medium-sized enterprises. In the UK, HazRed was co-sponsored by the Environment Agency, Scottish EPA, Envirowise, Waste Recycling Group and others. They tracked and targeted areas of highest hazardous waste arisings and impact across focus sectors including pharmaceuticals, printing, automotive and construction. Training workshops were run and specialist advisors sent to specific businesses. Measures taken included removal of such substances as chromium, cyanide and volatile organic compounds from protective finishes, paints, strippers, inks and cleaning fluids.

Business Benefits

- Some 1,200 tonnes of hazardous waste were diverted from landfill and savings to business totalled more than £440,000.

Drivers

- Businesses saw their involvement in HazRed as a way not only to save costs but also to ensure compliance with ever more stringent hazardous waste regulation.
- One company wanted to participate because taking action to limit environmental impact was 'a central part' of its strategy. Another pointed out that customers working towards their own sustainability targets, including the standard ISO 14001, expected suppliers to demonstrate a similar commitment.

Key Elements for Success

- The backing of the Environment Agency has been crucial to the success of HazRed. The Agency maintains an interest with schemes such as the European Pathway to Zero Waste targeting construction and other high-impact sectors.
- Recognising that larger companies are better placed to benefit from the environmental guidance and exploit advances in clean technology, the HazRed project deliberately targeted SMEs.
- Various communications tools were used to recruit companies and influence behaviour including sector champions, workshops, member communications within trade associations, regional and national press, Project Partner events, websites and newsletters.

4 Behavioural Aspects

4.1 Attitudes

As discussed above, widespread adoption of Lean Management in the automotive sector has led to a culture receptive to waste prevention: Scrap or defective products are generally seen as significant costs, and measures are taken to reduce them. Accordingly, waste prevention is seen as an operational issue rather than an environmental one (1).

With this degree of commercial sensitivity, the automotive sector is somewhat guarded in releasing data on waste prevention. On the other hand, the freely available information regarding fuel efficiency (waste in use) reflects both the move of the industry to a more life-cycle oriented approach, and the topicality of the issue with the public. This may lead to a shift to consider waste generation, and ultimately prevention if it can be placed within a similarly pressing set of objectives.

4.2 Motivators

Evidence has been found for the following incentives of waste prevention:

- reduction of cost
- reduction of company liability/risk.

Reduction in cost is the main driver for waste prevention in the automotive sector and is culturally embedded. A statement from an industry leader describes this point:

"[with waste minimisation] *we drive the cost down and drive the waste down so it is self-fulfilling, it works, you do not have to bring in a waste police in effect."* (J. Hardcastle/Nissan (1)).

Apollo's change of repair strategy (22) and the widespread use of retreaded tyres in commercial fleets (37) are other examples of cost pressure leading to waste prevention activities. An important aspect of cost savings by waste prevention is that these are usually easily determined and may be a powerful incentive in suggestion schemes involving cash awards for employees (NUMMI (12)). It should be noted, however, that waste prevention is a consequence of these activities and not the reason that they are performed. From the company's perspective, environmental benefits such as solid and hazardous waste reduction are seldom sufficient to justify the business case for process improvements. Indeed, the environmental benefits are typically small in comparison to gains from improved productivity and companies often do not to track them, so that that good information on waste prevention is relatively hard to come by (11).

Waste prevention can also be employed as a strategy to **reduce a company's liability and risk** of prosecution (14). For SMEs, compliance with regulation is a considerably more important driver than waste prevention (24).

4.3 Barriers

Evidence has been found for the following barriers to waste prevention in the automotive sector under the following broad headings:

1. lack of focus
2. competition from recycling alternatives

3. lack of know-how
4. lack of economic incentives.

A barrier to designing out waste is the current **focus of the automotive sector on improving the energy efficiency** of the vehicles. The sustainability reports of leading companies in the sector reveal that the dominating environmental topic is the energy consumption of vehicles in their use phase, i.e. fuel efficiency of cars. Waste is mainly reported in the context of 'zero waste to landfill' and recycling (e.g. Honda (41), Nissan (42)), and in one case waste is not reported at all (Ford (43)). An exception is Toyota, which does additionally report on 'discarded material', which includes all materials not recycled within the company (5).

Successful recycling is a barrier to waste prevention in the automotive sector as it offers an alternative solution for the waste problem and reduces the pressure to improve. An example is the termination of a project to create a design tool to ensure compliance with the EU End of Life Vehicles Directive (which required a mandatory minimum recyclability level for all cars) and to increase the suitability of a car for re-use and remanufacturing. The project failed because of the success of shredder technology that enabled compliance without any 'eco-design' (29). In another example, internal recycling of waste may lead to a company's misperception of not having any waste problem, even though waste prevention efforts could lead to significant cost savings (44).

Especially in SMEs, **lack of the know-how** may prevent the implementation of both Lean Management and waste prevention. Consultants offering waste audits to identify low-hanging fruits can be of value for such companies (16). Additionally, due to different definitions of 'waste' in Lean production and environmental sciences, even experienced practitioners of Lean methodology are often unaware of best practices in process-specific pollution prevention and waste minimization ideas and techniques (11). This issue is partly caused by the mentioned 'blind spots' of Lean methodology regarding substitution of hazardous substances and life-cycle aspects.

A significant barrier to waste prevention in the vehicle repair sector is the **lack of an economic incentive**. This can be due to repair shops' pricing model based on the value of exchanged parts, which renders actual repair of damaged parts less attractive (36). Additionally, spare part manufactures may oppose a shift towards repair as it leads to a reduction in sales of components (22).

4.4 Enablers

In an industry such as automotive where global operations operate from centralized headquarters, a key enabler is the **commitment of a parent company**. Regional outposts of multinational enterprises will comply and implement waste prevention programmes based on policies set at the head office; a good example of this is the actions taken by Bosch (22).

Additionally, the examples involving SMEs indicate the need of SMEs to obtain **business support** especially to identify waste (e.g. waste audits) and to learn and to introduce best practices. On the other hand multinational companies seem to have acquired the necessary expertise themselves, as the examples of waste prevention are mostly 'in-house' and have been achieved without support from the outside.

5 Conclusions

5.1 Learning

- **Based on the case studies and data identified, most initiatives to reduce waste in the automotive sector appear to be voluntary and driven by competitive pressure to reduce the costs of operation.** The main cost saving achieved from waste prevention are due to less raw material being purchased and reduction in re-work costs. The disposal costs (e.g. Landfill Tax or incineration costs for hazardous wastes) are an additional incentive. However, they can be easily minimised by achieving high recycling rates and do not necessarily push the waste prevention agenda.

- **Two main areas of waste prevention were identified:**

  - Waste prevention as a by-product of Lean activities aimed at improving throughput, quality and use of capital.

  - Waste prevention as part of projects to improve environmental and health/safety-sensitive processes (e.g. painting). Painting and cleaning activities have focused on minimising hazardous waste. Due to regulatory pressure (both environmental and workplace health and safety) significant improvements have been achieved.

- **Lean management appears to be a strong basis for waste prevention.** It fosters a culture of continuous improvement, involves shop-floor employees and targets preventing problems rather than rectifying them. Even though from an environmental point of view there are 'blind spots' in the Lean approach (e.g. hazardous materials, life-cycle approach) these shortcomings can be overcome by providing incentives to companies and information to Lean practitioners. Similarly, because Lean does not explicitly target waste prevention, we found counter-examples of increases in waste generation in order to satisfy other Lean objectives. However, the strong customer focus included in Lean implies that this methodology will be most effective once waste prevention is considered of value to the customer.

- **SMEs often lack the expertise and knowledge both with respect to Lean management and best practice in waste prevention** and have been the main target for business support. Such business support has come either from larger companies in the supply chain or via bodies with public funding. However, a report from the US EPA states that even large companies may lack the knowledge of best practices of waste prevention, especially where they apply to problems of avoiding hazardous substances and life-cycle aspects (40).

- **We found limited evidence for waste prevention by eco-design.** The focus in eco-design has largely been to reduce the CO_2 emissions of vehicles in use. Light-weighting has been largely used to partially offset increases in vehicle weight due to addition of convenience features (4). Reduction of hazardous content has received attention due to its ability to facilitate de-pollution and recycling at end of life.

- **Examples of product/service innovation such as re-use and remanufacturing have been found** in the fleet management of commercial vehicles (e.g. lorries, construction vehicles, tyres for commercial vehicle fleets). Most vehicle manufacturers have component remanufacturing services linked to (and limited to) their own dealership and supply chains. These are driven by cost saving; they have limited material waste saving but large energy-saving due to reduction of metal recycling. However, they do not yet appear to be widespread outside of fleet management.

5.2 Insights

The main examples of policy intervention to foster process improvements involve SMEs, which often lack the necessary know-how.

The automotive sector has attached more priority to landfill diversion and materials recovery targets under the EU End of Life Vehicle Directive than to waste prevention. Recycling systems and efficient shredder technologies have therefore developed to suit. Changing the way companies report waste away from the existing focus on diversion from landfill to a more complete picture by including waste generation could mitigate the problem of recycling being seen as the sole measure.

There are examples of using re-used and remanufactured parts for car repairs, but there does not appear to be sufficient motivation to promote this activity and abandon the prevalent strategy of substituting damaged parts by completely new ones despite some support from insurance companies.

Business support is expected to be very helpful, especially for SMEs. However, it needs to be structured and in depth because the automotive industry is process intensive and developing cleaner production strategies cannot generally be copied from one company to another (45).

In summary, the automotive sector is seen as both responsive to the current public environmental debate and capable of improving its processes. As the issue of waste has so far been framed as a disposal problem, the sector has made impressive progress towards 'zero waste to landfill' and recycling rates. Shifting the debate towards waste prevention is expected to give extra momentum to such initiatives in this sector.

5.3 Research Gaps

The following five research topics have been identified:

- The evidence shows increased waste generation by the sector as a whole with reduced waste by some. However, **the reasons for differential company behaviour bear further investigation.**

- Of the available case studies, most of them are from operations overseas and **it is not clear whether the same initiatives have been implemented here in the UK.** This is an important point to note; although there are no major UK-owned car manufacturers, there is a significant manufacturing base in the UK and further research into their activities could be worthwhile.

- **More research on the range of waste prevention performance across vehicle manufacturers and on the depth of take-up in the Tier 1 suppliers would be highly instructive.** Their commitment to Lean thinking is perceived as high and their factories are known to be very similar. This means that comparison research can be especially powerful.

- The arguments around environmental benefits of initiatives in the sector are often made in a narrow context rather than a whole life cycle consideration. **Insight into whether, based on the current state, it is better for the environment to target waste prevention, recycling or fuel efficiency would be beneficial for setting sector priorities** in respect of **whole vehicles**. (This does not detract from general efforts to increase process efficiencies and light-weighting of components in general.)

- The emergence of electric vehicles will offer radically different challenges in all life phases of vehicles. **How waste prevention opportunities will change, or could be actively managed, for hybrid and pure electric vehicles would be a significant contribution to road-mapping of future transport solutions and their impacts.**

6 Bibliography

1. **House of Lords.** *Waste Reduction Vol II: Evidence.* London : House of Lords, 2008. id 398.

2. **Clegg, A.J., Staikos, T. and Backhouse, C.J.** Potential for vehicle weight reduction using a new ductile cast iron. [book auth.] Bernard Hohn. *Design and Manufacture for Sustainable Development 2003.* Bury St. Edmunds : Professional Engineering Publishing, 2003.

3. **Business in the Community.** Toyota Motor Manufacturing (UK) Ltd-Achieving zero waste to landfill. *Business in the Community.* [Online] 2004. [Cited: 2 November 2010.] http://www.bitc.org.uk/resources/case_studies/afe256envtoyota.html. id 785.

4. **Morley, N., et al.** *Product Lightweighting-A strategy to deliver a sustainable economy?* Chester : C-Tech Innovation Ltd, 2007. id 608.

5. *Toyota Sustainability Report 2010.* s.l. : Toyota Motor Corporation, 2010. id 658.

6. **The Society of Motor Manufacturers and Traders (SMMT).** *11th annual sustainability report - SMMT.* London : SMMT, 2010. id 607.

7. **Oakdene Hollins and Grant Thornton.** *Quantification of the business benefits of resource efficiency.* London : Defra, 2007. id 32.

8. **Urban Mines.** *Potential For Resource Efficiency Savings For Businesses.* s.l. : Department for Business, Innovation and Skills, 2010. id 5.

9. **Owen, A.** *Case Studies of Waste Prevention Policies.* London : SMMT, 2010. id 771.

10. **EEF.** *Resource efficiency - Business benefits from sustainable resource management.* London : EEF, 2009. id 341.

11. **Ross & Associates Environmental Consulting, Ltd.** *Lean Manufacturing and the Environment: Research on Advanced Manufacturing Systems and the Environment and Recommendations for Leveraging Better Environmental Performance.* s.l. : U.S. Environmental Protection Agency, 2003. id 107.

12. **Rupp, S.E. and Vigil, S.A.** *Source Reduction and Recycling Programs at a Joint Venture Automobile Assembly Plant.* s.l. : Air & Waste Management Association, 1996. id 821.

13. **Canadian Vehicle Manufacturers' Association.** *Canadian Automotive Manufacturing Pollution Prevention Project.* Toronto : CVMA, 2005. id 782.

14. **Division of Pollution Prevention and Environmental Assistance.** Auto Body Restoration and Painting-A Success Story in Waste Reduction 1992-93. *DPPEA.* [Online] online, 1995. [Cited: 27 October 2010.] http://www.p2pays.org/ref/07/06582.htm. id 614.

15. *Cleaner production and profitability: analysis of 134 industrial pollution prevention (P2) project reports.* **Cagno, E., Trucco, P. and Tardini, L.** 2005, Journal of Cleaner Production, Vol. 13, pp. 593-605. id 409.

16. **Department for Business, Innovation and Skills.** *Practical Resource Efficiency Savings - Case Studies.* s.l. : BIS, 2009. id 333.

17. **Envirowise.** *Hazardous waste review steers automotive company towards cost savings - CS498.* Didcot : Envirowise, 2005. id 939.

18. **Environmental Technology Best Practice Programme.** *Choosing and Managing Re-usable Transit Packaging.* s.l. : Environmental Technology Best Practice Programme, 1998. id 700.

19. **Frater, L.B.** *Commercial and Industrial Waste Survey Wales 2003.* Cardiff : ESRC Centre for Business Relationships, Accountability, Sustainability & Society, 2006. id 339.

20. *Informing Packaging Design Decisions at Toyota Motor Sales Using Life Cycle Assessment and Costing.* **Early C., et al.** 4, 2009, Journal of Industrial Ecology, Vol. 13, pp. 592-606. id 779.

21. **Stop Waste.** *Toyota Logistics Services.* s.l. : Stop Waste, 2005. id 816.

22. **Earthshine Solutions.** *Global Research Project: "In Search of Sustainable Business" Apollo Motor Group.* London : Earthshine Solutions, 2010. id 392.

23. **Reliable Plant.** Toyota eliminates 1.7 million pounds of hazardous waste. *Reliable Plant.* [Online] [Cited: 9 November 2010.] http://www.reliableplant.com/Articles/Print/5661. id 609.

24. *Survey of Risk Reduction and Pollution Prevention Practices in the Rhode Island Automotive Refinishing Industry.* **Enander, R.T., Gute, D.M. and Missaghian, R.** 1998, American Industrial Hygiene Association Journal, Vol. 59, pp. 478-489. id 825.

25. **OCEAT.** *Trimac Transportation.* s.l. : Toronto Region Sustainability Program. id 781.

26. **Effizienz-Agentur NRW.** *TITAL GmbH: Innovativer Schwerkraftgussofen für Titangroßbauteile senkt Material- und Energieeinsatz.* Duisburg : EFA, 2009. id 579.

27. **NC Division of Pollution Prevention and Environmental Assistance's.** *North Carolina Lube Oil By-Pass Filter Project.* s.l. : DPPEA. id 612.

28. **Zirker, L., Francfort, J. and Fielding, J.** *Oil Bypass Filter Technology Evaluation.* s.l. : U.S. Department of Energy, 2006. id 627.

29. **DF Auto.** *Layman's Report: DF Auto Life05 Env/000500.* s.l. : Galway Mayo Institute of Technology. id 695.

30. **BMW.** *Fahrzeugrecycling-Nachhaltigkeit im Fokus.* Munich : BMW Group, 2009. id 869.

31. **Mercedes.** *All-new Mercedes-Benz E-Class awarded environmental certificate by TÜV Süd.* s.l. : Mercedes-Benz Australia/Pacific Corporate Communications, 2009. id 870.

32. *Life Cycle Assessment of Lightweight and End-of-Life Scenarios for Generic Compact Class Passenger Vehicles.* **Schmidt W.P., et al.** 6, Landsberg : s.n., 2004, The International Journal of Life Cycle Assessment, Vol. 9, pp. 405-416. id 603.

33. **Griffith, C.** *Toxics in Vehicles: Mercury.* s.l. : Ecology Center, 2001. id 611.

34. **Toyota Industries Corporation.** *Toyota-Social and Environmental Report 2007.* s.l. : Toyota Industries Corporation, 2007. id 818.

35. **Parker, D. and Butler, P.** *An Introduction to Remanufacturing.* Aylesbury : Centre for Remanufacturing and Reuse, 2007. id 657.

36. **Janssen, B.** *The RESPECT project: RE-use of Second-hand car comPonEnts iin Company car fleeTs.* s.l. : LIFE. id 688.

37. *The economics of tire remanufacturing.* **Ferrer, G.** 1997, Resources, Conservation and Recycling, Vol. 19, pp. 221-255. id 403.

38. **Kauffman-Johnson, J., et al.** *Chemical Management Services Industry Report 2004.* San Francisco : Trust for Conservation/Chemical Strategies Partnership, 2004. id 961.

39. *Lean Production and EMSs: Aligning Environmental Management with Business Priorities.* **Tice, J., Ahouse, L. and Larson, T.** s.l. : Environmental Quality Management, 2005, Vol. Winter 2005, pp. 1-12. id 827.

40. **Ross & Associates Environmental Consulting, Ltd.** *Pursuing Perfection: Case Studies Examining Lean Manufacturing Strategies, Pollution Prevention, and Environmental Regulatory Management Implications.* s.l. : U.S. Environmental Protection Agency, 2000. id 293.

41. **Honda of the UK Manufacturing Ltd.** *Honda of the UK Manufacturing Ltd Safety and Environment Report 2009.* Swindon : Honda of the UK Manufacturing Ltd, 2010. id 332.

42. **Nissan.** *Nissan Sustainability Report 2009-Nissan's Approach to CSR.* s.l. : Nissan, 2009. id 660.

43. **Ford.** *Ford - Blueprint for Sustainability.* Dearborn : Ford, 2010. id 659.

44. *Benchmarking aluminium die casting operations.* **Tharumarajah, A.** 2008, Resources, Conservation and Recycling, Vol. 52, pp. 1185–1189. id 835.

45. *Cleaner production and eco-efficiency initiatives in Western Australia 1996-2004.* **van Berkel, R.** 2007, Journal of Cleaner Production, Vol. 15, pp. 741-755. id 413.

Note: The id numbers at the end of the bibliographic references refer to the source file id number stored at www.infinifile.org.uk. You can access these sources for free, using project id 246 in conjunction with the file id when prompted. Requires registration. The adjacent QR code will take you to the site if you have the smart-phone QR reader app (many are free).

Disclaimer:
Oakdene Hollins Ltd and Brook Lyndhurst Ltd believe the content of this report to be correct as at the date of writing. The opinions contained in this report, except where specifically attributed, are those of Oakdene Hollins Ltd and Brook Lyndhurst Ltd. They are based upon the information that was available to us at the time of writing. We are always pleased to receive updated information and opposing opinions about any of the contents.

The listing or featuring of a particular product or company does not constitute an endorsement by Oakdene Hollins or Brook Lyndhurst, and we cannot guarantee the performance of individual products or materials. This report must not be used to endorse, or suggest Oakdene Hollins' or Brook Lyndhurst's endorsement of, a commercial product or service.

All statements in this report (other than statements of historical facts) that address future market developments, government actions and events, may be deemed "forward-looking statements". Although Oakdene Hollins and Brook Lyndhurst believe the outcomes expressed in such forward-looking statements are based on reasonable assumptions, such statements are not guarantees of future performance: actual results or developments may differ materially. Factors that could cause such material differences include emergence of new technologies and applications, changes to regulations, and unforeseen general economic, market or business conditions.

We have prepared this report with all reasonable skill, care and diligence within the terms of the contract with the client. Although we have made every reasonable effort to ensure the accuracy of information presented in this report, neither Oakdene Hollins nor Brook Lyndhurst can expressly guarantee the accuracy and reliability of the estimates, forecasts and conclusions herein. Factors such as prices and regulatory requirements are subject to change, and users of the report should check the current situation. In addition, care should be taken in using any of the cost information provided as it is based upon specific assumptions (such as scale, location, context, etc.). Clients should satisfy themselves beforehand as to the adequacy of the information in this report before making any decisions based on it.

Oakdene Hollins Ltd
Pembroke Court
22-28 Cambridge Street
Aylesbury
Buckinghamshire
HP20 1RS

T: +44(0)1296 423915
E: admin@oakdenehollins.co.uk
www.oakdenehollins.co.uk
www.remanufacturing.org.uk

Registered in England No. 2937129