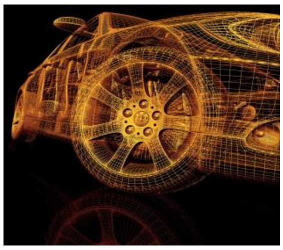
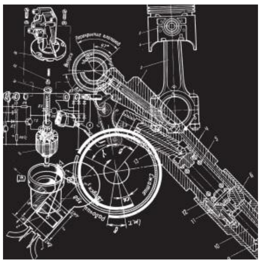
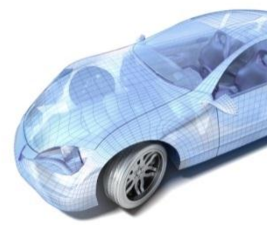
Best Environmental Management Practice in the Car Manufacturing Sector

Background Report: Preparatory findings to support the development of an EMAS Sectoral Reference Document



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Contact project manager:

Gena Gibson
Ricardo-AEA Ltd
Marble Arch Tower, 55 Bryanston Street, London W1H 7AA

t: +44123 575 3164

e: Gena.Gibson@ricardo-aea.com

Ricardo-AEA is certificated to ISO9001 and ISO14001

Authors:

Gena Gibson, Richard Woolley, Sujith Kollamthodi, James Harries (Ricardo-AEA)

Peter Wells (CAIR)

Date:

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Ricardo-AEA reference

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1 Introduction

1.1 Context and overview

This background report provides an overview of techniques that may be considered to be **Best Environmental Management Practices** (BEMPs) in the passenger car manufacturing sector. The document was developed on the basis of desk research, interviews with experts, site visits and discussions with technical experts via the forum of an appointed Technical Working Group (TWG).

This background report is intended to represent early findings that will be further developed through discussions with the TWG, according to a structured process outlined by the European Commission. Further information on the process can be found in the guidelines on the ***"Development of the EMAS Sectoral Reference Documents on Best Environmental Management Practice"*** (European Commission, 2014), which are available online[1].

The outcome of the TWG discussions will be a finalised Sectoral Reference Document (SRD), as required under the European EcoManagement and Audit Scheme (EMAS). EMAS was introduced on a voluntary basis in 1993 in order to promote continuous improvements in the environmental performance of industrial activities. The revision to EMAS in 2009 (EC No. 1221/2009) introduced a particular focus on promoting best environmental management practices. To support this aim, the European Commission's Joint Research Centre (JRC) is producing SRDs to provide information and guidance on BEMPs in several priority sectors, including the car manufacturing sector.

Nevertheless, it is important to note that the guidance on best practices is not only for EMAS participants, but rather it is intended to be a useful reference document for any relevant company that wishes to improve its environmental performance. Key stakeholders who may benefit from this guidance and contribute to its development include experts in the following sectors:

- **Car manufacturing processes**: includes a broad range of stakeholders involved at all stages of the supply chain, such as:
    - Car manufacturers and suppliers to car manufacturers,
    - Equipment suppliers,
    - Researchers and NGOs.
- **End-of-life vehicle (ELV) treatment**: effective implementation of BEMPs often involves collaboration between several stakeholder groups:
    - Car manufacturers and suppliers to car manufacturers,
    - ELV collection networks,
    - ELV depollution, dismantling and treatment facilities,
    - Recycling and waste management firms.

BEMPs encompass techniques, measures or actions that can be taken to minimise environmental impacts. These can include technologies (such as more efficient machinery) and organisational practices (such as staff training).

An important aspect of the BEMPs described in this document is that they are proven and practical, i.e.:

- They have been implemented at full scale by several organisations (or by at least one organisation if replicable/applicable by others);
- They are technically feasible and economically viable.

That is, BEMPs are demonstrated practices that have the potential to be taken up on a wide scale in the car manufacturing sector, yet at the same time are expected to result in exceptional environmental performance compared to current mainstream practices.

[1] http://susproc.jrc.ec.europa.eu/activities/emas/documents/DevelopmentSRD.pdf

A standard structure is used to outline the information concerning each BEMP, as shown in Table 1-1.

Table 1-1: Information gathered for each BEMP

Category	Type of information included
Description	Brief technical description of the BEMP including background and details on how it is implemented
Achieved environmental benefits	Main potential environmental *benefits* to be gained through implementing the BEMP
Environmental indicators	Indicators and/or metrics used to monitor the implementation of the BEMP and its environmental benefits
Cross-media effects	Potential *negative* impacts on other environmental pressures arising as side effects of implementing the BEMP
Operational data	Operational data that can help understand the implementation of a BEMP, including any issues experienced. This includes actual and plant-specific performance data where possible.
Applicability	Indication of the type of plants or processes in which the technique may or may not be applied, as well as constraints to implementation in certain cases
Economics	Information on costs (investment and operating) and any possible savings (e.g. reduced raw material or energy consumption, waste charges etc.)
Driving force for implementation	Factors that have driven or stimulated the implementation of the technique to date
Reference organisations	Examples of organisations that have successfully implemented the BEMPs
Reference literature	Literature or other reference material cited in the information for each BEMP

Sector-specific Environmental Performance Indicators and Benchmarks of Excellence are also derived from the BEMPs. These aim to provide organisations with guidance on appropriate metrics and levels of ambition when implementing the BEMPs described.

- **Environmental Performance Indicators** represent the metrics that are employed by firms to monitor and benchmark their environmental performance. The suggested indicators were developed to improve linkages with other policies through the use of common metrics.
- **Benchmarks of Excellence** represent the highest environmental standards that have been achieved by firms implementing each related BEMP. These aim to allow firms to understand the potential for environmental improvement at the process level.

1.2 Role and purpose of this document

The present report provides a basis to be used by the Technical Working Group for the elaboration of the Best Practice Report containing the technical basis for the Sectoral Reference Document (SRD). The implementation of techniques contained in these documents is on a voluntary basis; however, their scope will cover a number of areas which are already the subject of voluntary but also mandatory standards and regulations.

Section 2.2.1 provides a more detailed description of the scope as well as the other relevant texts, while **section 3.5.4** presents references of direct relevance to specific aspects of the car manufacturing process.

In order to maximise the added value and minimise the overlaps of the SRD development with other policy instruments/standards/regulations, the following points should be kept in mind:

- SRDs are designed in reference to activities/processes, rather than products. In the present case, the focus of the document, is on car manufacturing (**M1 category** vehicles[2]), as set out in the Commission Communication (2011/C 358/02), which identified a list of priority sectors for the adoption of SRDs. Since car manufacturing can be done in conjunction with, or at least present extensive similarities to, other types of vehicles (in particular vans but also larger vehicle categories), many BEMPs and techniques will be directly applicable or of interest to the manufacture of these vehicles. However, they have been developed primarily based on practice in the car manufacturing sector.
- There is a broad range of existing regulation covering the environmental impact of the sector, aimed both at the product- and activity/process- levels. In particular, major relevant texts include:
  - Regulations (EC) regarding the *use phase*, at product level such as Euro 5 and 6 (No. 715/2007 and 692/2008) or manufacturer level regulation e.g. on CO_2 (No. 443/2009). The use phase of vehicles is explicitly out of the scope defined for this work.
  - Best Available Technique (BAT) Reference Documents (or BREFs) formulated under the Industrial Emissions Directive, which set out references for setting Industrial Emissions Directive (IED) permit conditions (of a binding nature). Many of these apply to some activities in the car manufacturing value chain, e.g. on Treatment of Surfaces with Organic Solvents or for Waste Treatment.
  - Directives relating to used cars such as the End-of-Life Vehicle directive (2000/53/EC) or "RRR" Directive (2005/64/EC).

More extensive references are provided in each section and a detailed overview is presented in Sections 2.2.1 and 3.5.4. The BEMP descriptions contained here, and which will form the basis of the forthcoming Best Practice report and SRD, will therefore be designed to cover additional practices that go beyond both the regulatory minimum, as well as going beyond common practices applied in the sector.

1.3 Structure of this document

- **Section 2** sets out the scope of general processes that are included in the study.
- **Section 3** provides overviews of the preliminary BEMPs relevant to the car manufacturing sector, identified according to the standard structure outlined above.
- **Section 4** provides overviews of the preliminary BEMPs relevant to the treatment of end-of-life vehicles (ELVs).

1.4 References for the introductory section

European Commission (2014). Development of the EMAS Sectoral Reference Documents on Best Environmental Management Practice: Learning from frontrunners. Available at: http://susproc.jrc.ec.europa.eu/activities/emas/documents/DevelopmentSRD.pdf (accessed 10/06/2014).

[2] As per Directive 70/156/EEC on type approval and amending regulations – M1 corresponds to passenger vehicles (≤8+1 occupants) and N1 to commercial vehicles ≤3.5t.

2 General background information on the car manufacturing industry

2.1 Sector overview

Europe is currently the second-largest producer of passenger cars in the world, accounting for 23% of global production in 2012 (14.6 million units), second only to China (15.5 million units in 2012) (OICA, 2013). The industry makes an important contribution to many of the EU's national economies. Around 2.2 million people are directly employed in the manufacture of motor vehicles in the EU (including commercial vehicles), and indirect employment along the whole value chain brings the total employment to around 12.9 million people – approximately 5% of the EU employed population (ACEA, 2013).

The car industry in Europe suffered heavily following the economic crisis, and production still has not recovered to its peak levels seen in 2007 (OICA, 2013). Nevertheless, the sector continues to play a major role in EU international trade. Motor car exports were worth €93.8 billion in 2011 (around 6% of total value of all extra-EU exports), while imports were worth around €24.2 billion (less than 2% of the total value of all extra-EU imports) (Eurostat, 2013). The majority of these exports are from Germany (around 60% of the total) and the UK (around 20%) (Eurostat, 2013).

In addition to the manufacture of cars, some environmental aspects of the treatment of End-of-life vehicles (ELVs) are also considered in this study. Since the average lifespan of a car in Europe is around 12 years (although this varies depending on the Member State), ELVs that are being treated today are (for the most part) cars that were manufactured many years ago. Official statistics report that around seven million units arise each year in the EU (Eurostat, 2013).

2.1.1 Composition of the sector

Table 2-1 provides an overview of the automotive industry sub-sectors according to the statistical classification of economic activities in the EU (NACE). The NACE code is the European standard industry classification system[3]. The total turnover of the automotive industry[4] - including manufacture of vehicles, bodies and components - was around €740 billion in 2010, and total value added was €141 billion (Eurostat, 2013).

Table 2-1: Overview of automotive industry sub-sectors (data for 2010)

Sub-sector	Turnover (€ billion)	Value added (€ billion)	Number of enterprises (thousands)	Employment (thousands)
Motor vehicle manufacture *NACE 29.10*	526	90	2.3	1,002
Manufacture of bodies for motor vehicles *NACE 29.20*	25	7	7.7	159
Manufacture of other parts for motor vehicles *NACE 29.32*	189	46	10.6	1,010

Source: (Eurostat, 2013)

Notes: NACE codes referenced above are indicative of the scope of activities relevant to the car manufacturing sector, but may also include other sectors. Data from Eurostat refer to individual enterprises, rather than business groups of manufacturers. Figures include manufacture of passenger cars and commercial vehicles.

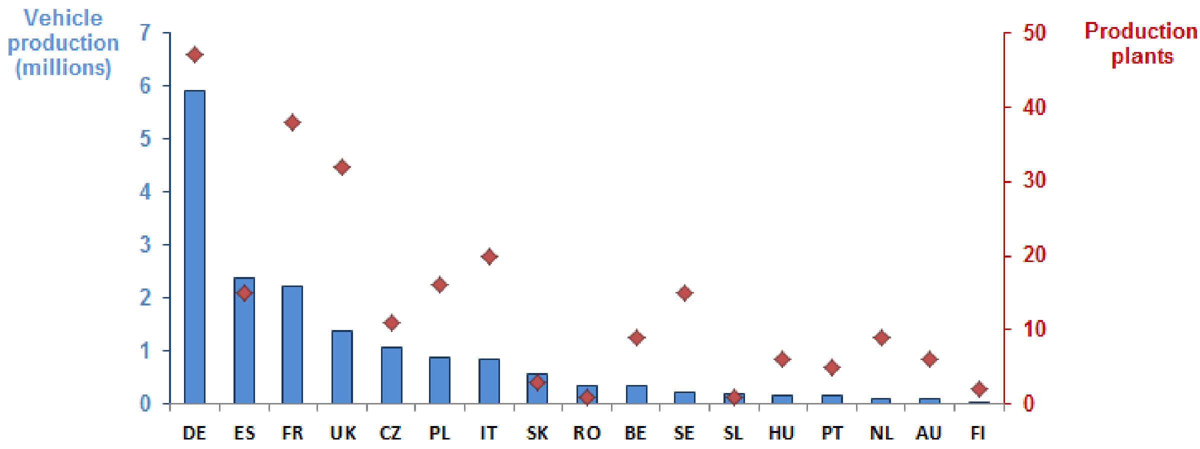
[3] See http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-RA-07-015/EN/KS-RA-07-015-EN.PDF
[4] Including passenger cars and commercial vehicles (vans, trucks and buses)

Precise figures for employment in the ELV sector are not available, as the activities involved are subsets of three wider areas: *Dismantling of wrecks* (NACE 38.31, including dismantling of ELVs for materials recovery), *Recovery of sorted materials* (NACE 38.32, including ELV shredding) and *Wholesale of waste and scrap* (NACE 46.77, including dismantling of ELV for obtaining and re-selling usable parts). ELVs are only a part of total shredder input, accounting for around 10% to 40% in many countries (Schneider et al, 2010).

2.1.2 Geographical distribution

Car production in Europe is concentrated in a small number of Member States. Figure 2-1 shows the volume of vehicle production and the number of production plants in each Member State. Germany is a clear leader (35% of total production in 2010). Other important producers include Spain (14%), France (13%), and the UK (8%), as well as the Czech Republic, Poland and Italy. The same countries are also the main producers of parts and components, although Central and Eastern European Member States such as Slovakia, Slovenia, Hungary and Romania are gradually gaining a higher share of total production, particularly with respect to parts and components.

Figure 2-1: Vehicle production and number of production plants per Member State in 2010



Source: (ACEA, 2013)

In total, there are around 230 vehicle production plants in Europe in 18 Member States (ACEA, 2013). Certain manufacturers have opened new manufacturing sites in Europe (mainly in Central and Eastern Europe) to take advantage of the lower production costs and the proximity to the Western European markets. While the majority of sites belong to European OEMs, others have also invested in new plants – for example, in the Czech Republic (Hyundai), Hungary (Suzuki) and Poland (Toyota) (Kawecka-Wyrzykowska, 2009).

Turnover and employment is also concentrated in a few Member States. Around 40% of total EU vehicle manufacturing turnover comes from Germany, and around 10% from France, while all other countries each account for less than 10% (Eurostat, 2013). Of the 2.2 million jobs in direct vehicle manufacturing, around 840,000 are based in Germany, 250,000 in France and between 100,000 and 200,000 each in the UK, Italy, Spain, Czech Republic and Poland (Eurostat, 2013).

Processing ELVs involves several stages that may take place at different facilities. In general, ELVs may be received by various types of Authorised Treatment Facilities (ATFs) for depollution (removal of liquids, airbags, batteries and other hazardous materials) and dismantling prior to shredding. These facilities include scrap yards, dismantling businesses, salvage operators and secondary metal businesses. The ELVs are typically passed on to shredding facilities once they have been depolluted and dismantled. Since shredding facilities involve large, capital intensive operations, they tend to be far fewer in number compared to ATFs. Indications of the number of ATFs and shredders in each Member State are provided in Table 2-2.

Table 2-2: Number of Authorised ELV Treatment Facilities (ATFs) and shredders in European countries

Member State	No. ATFs (incl. shredders)	Year of data source
Austria	216 (6 shredders)	2008
Belgium	120 (12 shredders)	2010
Cyprus	2	2008
Czech Republic	80-100	2005
Germany	1261 (36 shredders)	2008
Denmark	210	2005
Spain	540	2005
Estonia	32 (1 shredder)	2010
Greece	56	2008
France	1,000	2005
Finland	235	2010
Hungary	150	2005
Italy	1,800	2005
Ireland	85	2008
Luxembourg	4	2005
Latvia	261	2005
Lithuania	43	2005
Malta	ND	-
Netherlands	418	2008
Portugal	45	2008
Poland	557 dismantlers	2007
Sweden	365	2008
Slovenia	20	2005
Slovakia	30	2005
UK	1,750	2010

Source: (Schneider et al, 2010)

Refurbishment and remanufacturing activities account for over 32,000 jobs in Europe (with the automotive sector representing the largest part of this activity) (Optimat, 2013).

A large number of used cars are exported from the EU each year, which reduces the number of ELVs that require treatment. It is estimated that up to five million used vehicles are scrapped unofficially and over one million used vehicles are exported to non-EU countries (Öko-Institut, 2012). According to Eurostat statistics, the countries with the highest number of ELVs are France (22% of the total in Europe, excluding Malta and Croatia) and the UK (18%) (Eurostat, 2013).

2.1.3 Environmental management in the car manufacturing sector

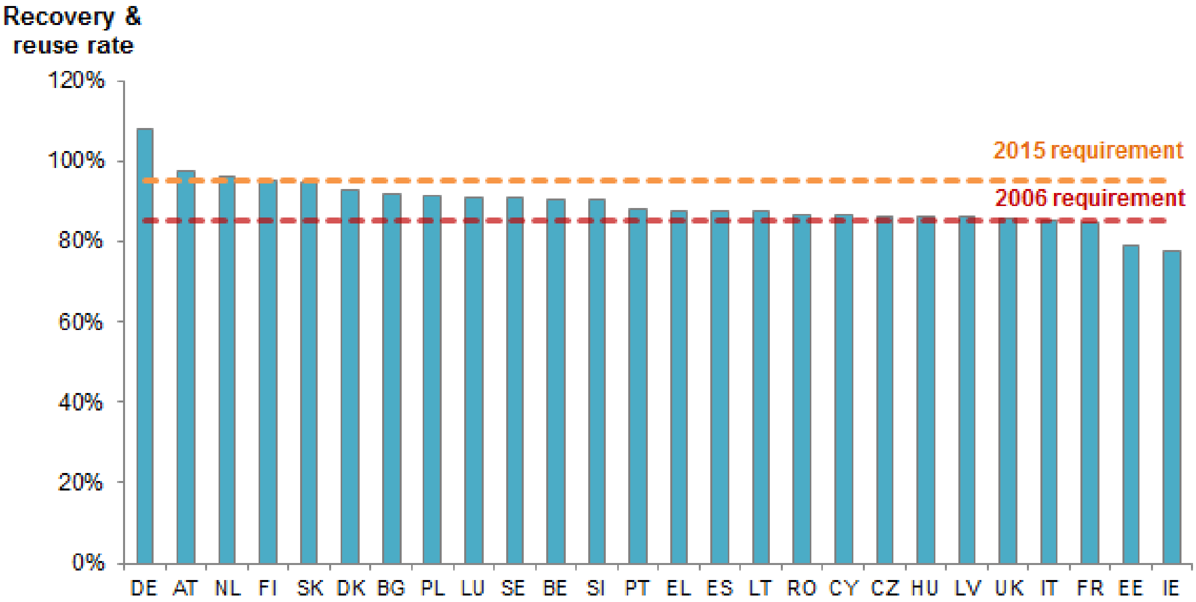
While car manufacturers are legally required to publish type-approval fuel consumption and CO_2 emission figures for their vehicles while *in use*, there is no equivalent requirement for publishing environmental performance data during the manufacturing stages.

Regarding the end-of-life stage, the End-of-Life Vehicles (ELV) Directive (2000/53/EC) has required that in each Member State an average of at least 80% of the mass of an ELV is reused or recycled and another 5% or more of its mass is energetically recovered. In 2015 the rates will increase to 85% and 10%, respectively. Even before the implementation of the ELV Directive, most Member States had recycling rates for ELVs of around 75%. This is largely because around 75% of a vehicle's weight is metal, for which recycling is usually economically attractive. Increasing the overall reuse and recycling rate further therefore requires a higher recycling rate of non-metallic fractions, which is typically less economically attractive and/or more technically challenging.

The most recent Eurostat data (see Figure 2-2) show that most countries exceed the 2006 requirement in the ELV Directive for reuse and recycling plus energy recovery, although many have not yet reached the 2015 target. However, analysis by Eurostat revealed considerable differences

regarding the data collection and evaluation by the Member States that suggest these aggregated figures are not entirely comparable (Schneider et al, 2010).

Figure 2-2: ELV recovery and reuse rate in the EU-27 in 2011



Source: (Eurostat, 2013)

Notes: Germany's rate temporarily exceeded 100% as the remaining ELV stocks which arose during the 2009 scrappage scheme were processed. Apparent non-compliance in Estonia and Ireland is likely to be the result of reporting issues (e.g. underestimates due to not including recycling of non-metals) that are expected to be resolved in future years.

European legislation in other areas is also relevant, such as:

- EU Directive 2006/66/CE on batteries requires a recycling rate of 50% for electric vehicle Lithium-Ion batteries. It also requires the recycling of 65% by average weight of lead-acid batteries and accumulators, including the recycling of the lead content to the highest degree that is technically feasible while avoiding excessive costs. The Directive does not specifically address nickel-metal hydride batteries that are sometimes used in hybrid cars.
- The Waste Oil Directive 75/439/EEC as amended by Directive 2000/76/EC is designed to create a system for collection, recovery and disposal of waste oils (including lubricant oils for vehicles, gearboxes and engines, hydraulic oils etc.).
- The REACH (Registration, Evaluation, Authorisation and Restriction of Chemical substances) Directive, which was enacted in June of 2007, includes regulations pertaining to substances of very high concern (SVHC). It addresses chromium, lead, mercury, brominated flame retardants, and phthalates, which are present in many polymers.

Other general EU legislation on waste can affect relevant activities in the automotive sector. These include (amongst others): Directive 1999/31/EC on the landfill of waste, Directive 2000/76/EC on the incineration of waste and Directive 94/62/EC on packaging and packaging waste.

2.2 General scope for this study

2.2.1 Scope definition at the sector level

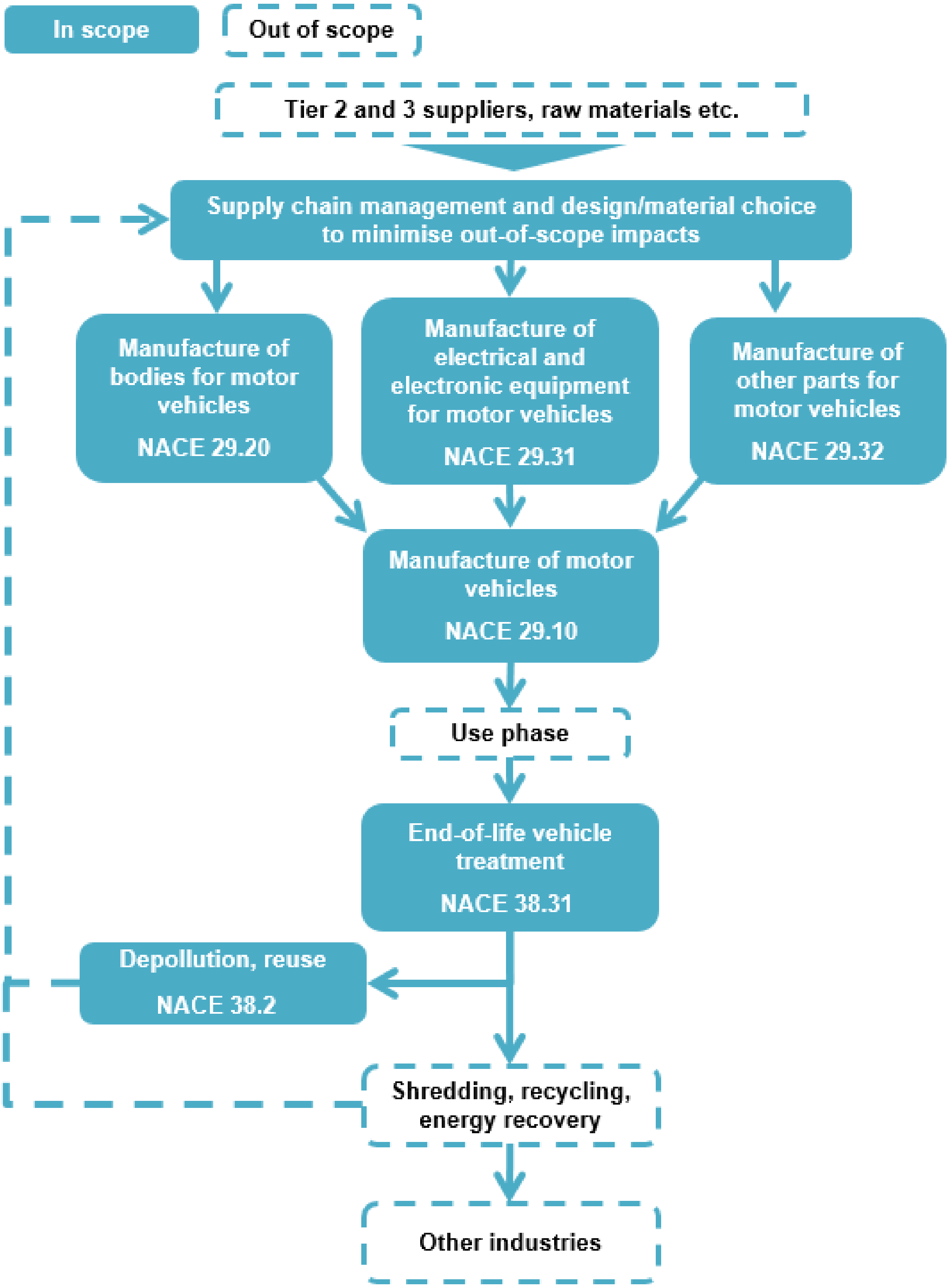
The scope definition for this study at the *sector level* takes into account environmental impacts throughout the value chain of a vehicle while aiming to avoid overlaps with other available guidance. The value chain, from parts manufacturing to end-of-life treatment, incorporates the following main aspects:

- **Manufacturing and assembly stages:** Including production of components, subassemblies and other equipment that is assembled in the final vehicle, as well as the manufacture of the vehicle body, engine etc. and final assembly. This includes operations typically carried out in-house by OEMs as well as externally by suppliers. Whilst a higher emphasis is placed on activities that take place within Europe, it is recognised that many important environmental impacts are generated along the supply chain in regions outside of Europe.
- **The end-of-life vehicle (ELV) stage**: Treatment of the vehicle at the end of its life, including dismantling and depollution of the vehicle before shredding or general recycling.

Vehicle manufacturers are known as Original Equipment Manufacturers (OEMs). There are a small number of major OEMs in the European market, although they typically manufacture a number of different brands. Automotive suppliers are generally categorised in ‘tiers’. Tier 1 describes suppliers delivering directly to OEMs, Tier 1 suppliers tend to supply some of the largest components or sub-assemblies (including powertrain, transmission and steering systems), and work in close collaboration with the OEMs. Tier 2 suppliers provide components to Tier 1 suppliers (pump units, bearing assemblies etc.). Finally, Tier 3 suppliers provide smaller components and raw materials to upper Tier suppliers or in some case the OEMs.

A high level overview of the scope of activities covered in this study is shown in Figure 2-3. A distinction between suppliers and OEMs is not made in this document, as the division of activities carried out varies depending on the organisations involved and their business models. In general, it can be said that the OEMs often (but not always) retain production of body panels and powertrain in-house, along with assembly and painting of the bodyshell, and attachment of assemblies and components to the painted bodyshell to produce the final vehicles. The majority of components and assemblies fitted to the vehicle (aside from the powertrain and body panels) are usually produced by suppliers.

Figure 2-3: High-level overview of sector-level scope for this study according to NACE (Rev.2)



Notes: The NACE code is the European standard industry classification system[5]. NACE codes referenced above are indicative of the scope of activities relevant to the car manufacturing and ELV sectors, but may also include other sectors.

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[5] See http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-RA-07-015/EN/KS-RA-07-015-EN.PDF

The entire lifecycle of the vehicle is represented in Figure 2-3, with certain aspects marked as *“out of scope”* for the following reasons:

- **Tier 2 and 3 suppliers, raw materials etc.:** The focus of this study will be on OEMs and Tier 1 suppliers, since these represent areas where the car manufacturing industry can have the most significant and direct influence over environmental impacts. Therefore, Tier 2 and 3 suppliers are considered only in terms of supply chain management and indirectly through vehicle design.
- **Primary material transformation stages:** (including primary production of metals, plastics, glass etc.) are already covered under the related studies on Best Available Techniques (BAT) reference documents, the so-called BREFs, that have been adopted under the Integrated Pollution Prevention and Control (IPPC) Directive (2008/1/EC) and the Industrial Emissions Directive (2010/75/EU). These reference documents are available online[6]. Further details and specific references to relevant documents are provided in *Section 3.5: Key manufacturing processes,* and in particular *subsection 3.5.4: Compendium of references for key manufacturing processes in the automotive sector.*
- **Main processes covered by other Sectoral Reference Documents on Best Environmental Management Practices:** These include several general industrial operations related to fabricated metal products, and electrical and electronic equipment. Further details and references are provided in *Section 3.5: Key manufacturing processes,* and in particular *subsection 3.5.4: Compendium of references for key manufacturing processes in the automotive sector.*
- **Use phase:** The use phase is very significant in terms of overall lifecycle impacts, but this phase is covered by other existing policies and the main focus of this study is on improving manufacturing processes at the organisational level. Therefore, impacts generated during vehicle use, maintenance and retail are not explicitly included; rather, they are considered in the cross-media effects in terms of potential trade-offs between environmental burdens in different life cycle stages.
- **Shredding, post-shredder treatment and general material recycling:** The focus of the study is on the depollution and reuse aspects of ELV treatment before the vehicle is shredded. Once the vehicle hulk reaches the shredder it is typically mixed with other waste streams and subject to more general recycling and recovery operations. The relevant processes are covered in the Best Available Techniques (BAT) reference document (*BREF) on waste treatment industries*, for which the latest revision is expected to be available online in the near future[7].

2.2.2 Main environmental impacts

The guidance in this document aims to provide practical advice on how to reduce environmental impacts at the *organisational level*, rather than at the product level. That is, it focusses on best practices for specific manufacturing or organisational processes regardless of the chosen technologies included in the vehicle (such as the type of powertrain or the vehicle segment). However, it is worth noting that the in-use phase accounts for a significant proportion of overall environmental impacts in most categories.

The main environmental impacts related to car manufacturing and ELV treatment include:

- **Energy consumption and climate change:** Energy is used throughout the processes involved in vehicle production and ELV treatment. Energy consumption is often associated with emissions of greenhouse gases (GHGs), which lead to global warming and climate change. GHGs primarily consist of carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4).
- **Resource use and waste production**: Higher levels of waste imply that more resources are consumed. Finite resources, security of supply and the environmental burdens of resource consumption are increasing concerns for many organisations, but of particular concern for the automotive industry is the need to balance the need to improve fuel efficiency while using materials that are recyclable at the ELV stage.

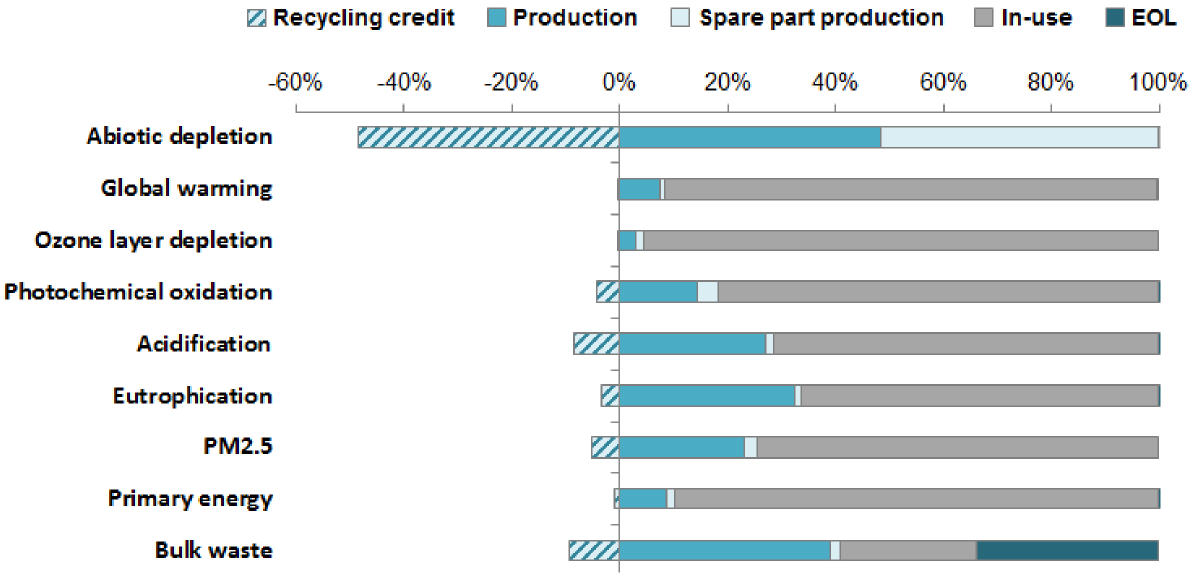
[6] http://eippcb.jrc.ec.europa.eu/reference/
[7] http://eippcb.jrc.ec.europa.eu/reference/

- **Water consumption:** The difference between the amount of liquid water input and waste water is the consumption. This accounts for freshwater withdrawals that are evaporated or incorporated in products and waste i.e. the water that is not available in liquid form for reuse immediately after it is consumed.
- **Emissions to air, soil and water**: includes any pollutants that could be released during car manufacturing and/or at the ELV stage – as such it encompasses a very broad range of possible issues. Specific substances include:
    - Acidification potential (AP): SO_2 and NO_x emissions are the main causes of acid deposition, which leads to changes in soil and water quality and damage to vegetation, buildings and aquatic life.
    - Eutrophication potential (EP): Eutrophication is a process whereby water bodies, such as lakes or rivers, receive excess chemical nutrients — typically compounds containing nitrogen or phosphorus — that stimulate excessive plant growth (e.g. algae).
    - Photochemical pollution (PCOP): The increased potential of photochemical smog events due to the chemical reaction between sunlight and specific gases released into the atmosphere. These gases include nitrogen oxides (NOx), volatile organic compounds (VOCs), peroxyacyl nitrates (PANs), aldehydes and ozone.
    - Particulate matter ($PM_{2.5}$): Inhaling particulate matter has been linked to asthma, lung cancer, cardiovascular problems, birth defects and premature death.

  Most of these substances are subject to regulatory limits (discussed below), and therefore the scope of the study will focus on instances where manufacturers have voluntarily exceeded their regulatory obligations.
- **Impacts on ecosystems and biodiversity:** Ecosystems refer to plant, animal, and microorganism communities and the non-living environment interacting as a functional unit. Biodiversity refers to the variety of animal and plant life within a region, which is crucial for the functioning of ecosystems.

Figure 2-4 shows the distribution of lifecycle impacts for a typical petrol car during different phases. Total lifecycle primary energy consumption, greenhouse gas (GHG) emissions and ozone depletion impacts are dominated by the in-use phase. In general, the share of impacts is similar for diesel vehicles, although there are some differences that are mainly due to the different fuel production and combustion processes (Nemry et al, 2008). Highly fuel-efficient vehicles such as plug-in hybrid electric vehicles and battery electric vehicles have the potential to reduce environmental impacts in most categories; however current studies indicate that the local electricity generation mix has a significant impact on this potential (Nemry et al, 2008). Thus, as the automotive industry moves toward more highly fuel-efficient vehicles, the relative environmental impacts in the production and end-of-life stages will become more important.

Figure 2-4: Share of lifecycle impacts for a typical petrol car (percentage attributable to different lifecycle stages)



Notes: Based on average characteristics derived from statistics of new cars sold in Europe. The main characteristics are: Euro 4 standard petrol car with an average lifespan of 12.5 years and annual mileage of 16,900km, vehicle weight 1,240kg (mid-size category).

Source: (Nemry et al, 2008)

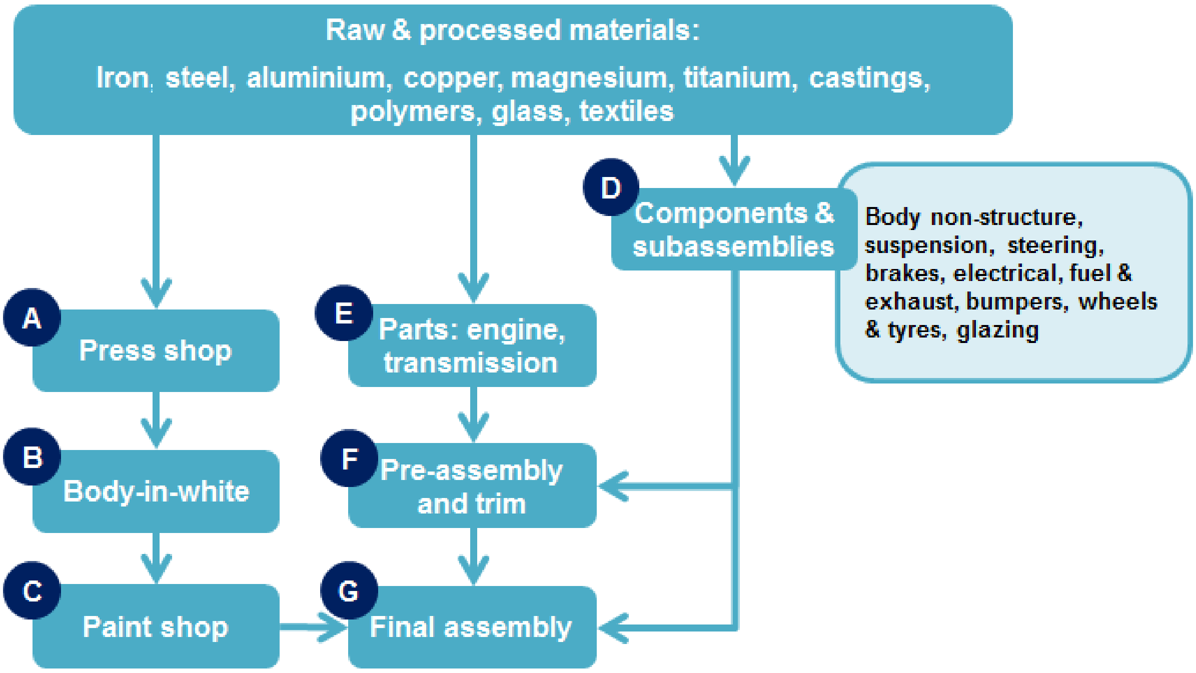
Given that the in-use phase accounts for a significant proportion of overall lifecycle impacts, it is worth emphasising the importance of adopting a lifecycle approach to decision-making to ensure that environmental impacts are reduced overall. This is especially important when considering trade-offs between different lifecycle phases, as well as between different impact categories. Therefore, while the in-use phase is not explicitly covered within this study, the "cross-media impacts" of each BEMP includes a review of possible benefits and trade-offs in other areas.

2.2.3 Processes involved in the manufacturing and end-of-life phases

Passenger vehicles are very complex, with up to 180,000 parts (Schmidt, 2007), and typically around 75% of a vehicle's value is derived from automotive suppliers (CLEPA, 2011). As such, it is necessary to prioritise the scope of the investigated BEMPs for this study in terms of their importance, i.e. processes that: contribute to a significant proportion of environmental impacts in one or more categories, and over which the actors in the car manufacturing industry could have significant influence.

A high level overview of the stages of manufacturing a car is shown in Figure 2-5 with a description of the processing stages.

Figure 2-5: High-level overview of car manufacturing stages



The stages include:

A. **Press shop:** The vehicle body is typically made of out stamped steel, although other materials are increasingly used to reduce weight (such as aluminium, plastics and carbon fibre).

B. **Body-in-white:** Production of vehicle body structure including closures. The separate panels are assembled by welding or other joining methods.

C. **Paint shop**: Application of interior and exterior paint and finish. The body is usually painted with several layers to protect it from corrosion

D. **Component and subassembly manufacturing (excluding powertrain and chassis):** There are a large number of components and subassemblies in a vehicle. These include the exterior trim (e.g. wheels, bumpers, trim, glazing), interior trim (e.g. seats, dashboards, trim, fascia/dashboard, carpets, steering wheel), and electrical and electronic components (e.g. engine control units, safety systems, battery control systems, entertainment systems).

E. **Manufacturing of powertrain and chassis:** The chassis of the vehicle is the main structure, and is usually made out of a pressed steel frame on which other components can be mounted – such as wheels, steering gear, power train (engine, transmission, drive shaft), brakes and exhaust system.

F. **Pre-assembly and trim:** Certain parts may be assembled separately before being joined with the car body in the final vehicle assembly

G. **Final assembly:** Assembly of finished vehicle.

At the ELV stage, there are two main steps that are of interest to this study:

1. **Depollution:** At the end-of-life facilities, fluids are drained and hazardous materials (such as batteries and airbags) are removed.
2. **Salvage and reuse:** Spare and core parts that can be reused or recycled are removed. The remaining body is fed into a shredder (processes beyond this point are out-of-scope for this study).

Processes that have a high or medium contribution to the total impacts in any of the above environmental impact categories are considered within the scope of the study. A summary is shown in Table 2-3.

Table 2-3: Summary of the scope of this study

Colour coding:

- (dark grey) High impact (>20% lifecycle impacts in this category excluding in-use phase)
- (light grey) Medium impact (10-20% of impacts)
- (white) Low impact (<10% of impacts)

Cell contents:

- ✓ Included in the scope of the study
- × Not included in the scope of the study

<table>
<tr><th>Processes</th><th>Energy consumption and climate change</th><th>Resource use and waste production</th><th>Water consumption</th><th>Emissions to air, water and soil</th><th>Ecosystems and biodiversity</th></tr>
<tr><td colspan="6">Manufacturing and assembly stage</td></tr>
<tr><td>Press shop</td><td>✓</td><td rowspan="2">(✓)
Included in cross-cutting processes</td><td>×</td><td>×</td><td>×</td></tr>
<tr><td>Body-in-white</td><td>×</td><td>×</td><td>×</td><td>×</td></tr>
<tr><td>Paint shop</td><td colspan="4">Covered by guidance under the Best Available Technology Reference Document (BREF) for Treatment of Surfaces with Organic Solvents[8]</td><td>×</td></tr>
<tr><td>Manufacture of powertrain and chassis</td><td colspan="4">Covered by forthcoming Sectoral Reference Document on Best Environmental Management Practices for fabricated metal products</td><td>×</td></tr>
<tr><td>Manufacture of other components</td><td colspan="4">Covered by Best Available Technology Reference Documents[9] (BREFs) for ferrous metals processing, iron and steel production, smitheries and foundries, non-ferrous metals processing manufacture of glass, polymers, ceramics and textiles</td><td>×</td></tr>
<tr><td>Assembly lines</td><td>×</td><td rowspan="2">(✓)
Included in cross-cutting processes</td><td>×</td><td>×</td><td>×</td></tr>
<tr><td>Plant infrastructure</td><td>✓</td><td>✓</td><td>(✓)
Included in cross-cutting processes</td><td>✓</td></tr>
<tr><td>Cross-cutting</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td colspan="6">End-of-life Vehicles (ELVs) stage</td></tr>
<tr><td>Depollution</td><td>×</td><td>×</td><td>×</td><td>×
(regulatory requirement)</td><td>×</td></tr>
<tr><td>Salvage and reuse</td><td>✓</td><td>✓</td><td>×</td><td>✓</td><td>×</td></tr>
<tr><td>Post-shredder treatment</td><td colspan="5">Covered by forthcoming guidance under the Best Available Technology Reference Document (BREF) on waste treatment industries[10].</td></tr>
</table>

Sources: The relative importance of each stage established from: (Sullivan, 2010)*;* (Galitsky & Worrell, 2008)*;* (Mercedes, 2009)*;* (Renault, 2011)*;* (Schweimer, 2000)*;* (Enertika, 2013)*;* (DEFRA, 2003)*;* (Schmidt, 2007), (Ford, 2007)*;* (GM, 2012)*;* (Environment Australia, 2002)*;* (Ai Group, no date)*;* (Volkswagen, 2012)*;* (GHK,

[8] Available online at http://eippcb.jrc.ec.europa.eu/reference/
[9] Available online at http://eippcb.jrc.ec.europa.eu/reference/
[10] Currently under revision. The existing version as well as the new version when available can be accessed online at http://eippcb.jrc.ec.europa.eu/reference/

2006); (Optimat, 2013); (Weiland, 2006); (Bras et al, 2012); (Warsen et al, 2011); (BMW Group, 2012); (Volvo, 2013); (VCS, 2013); (ACEA, 2010); (Schneider et al, 2010).

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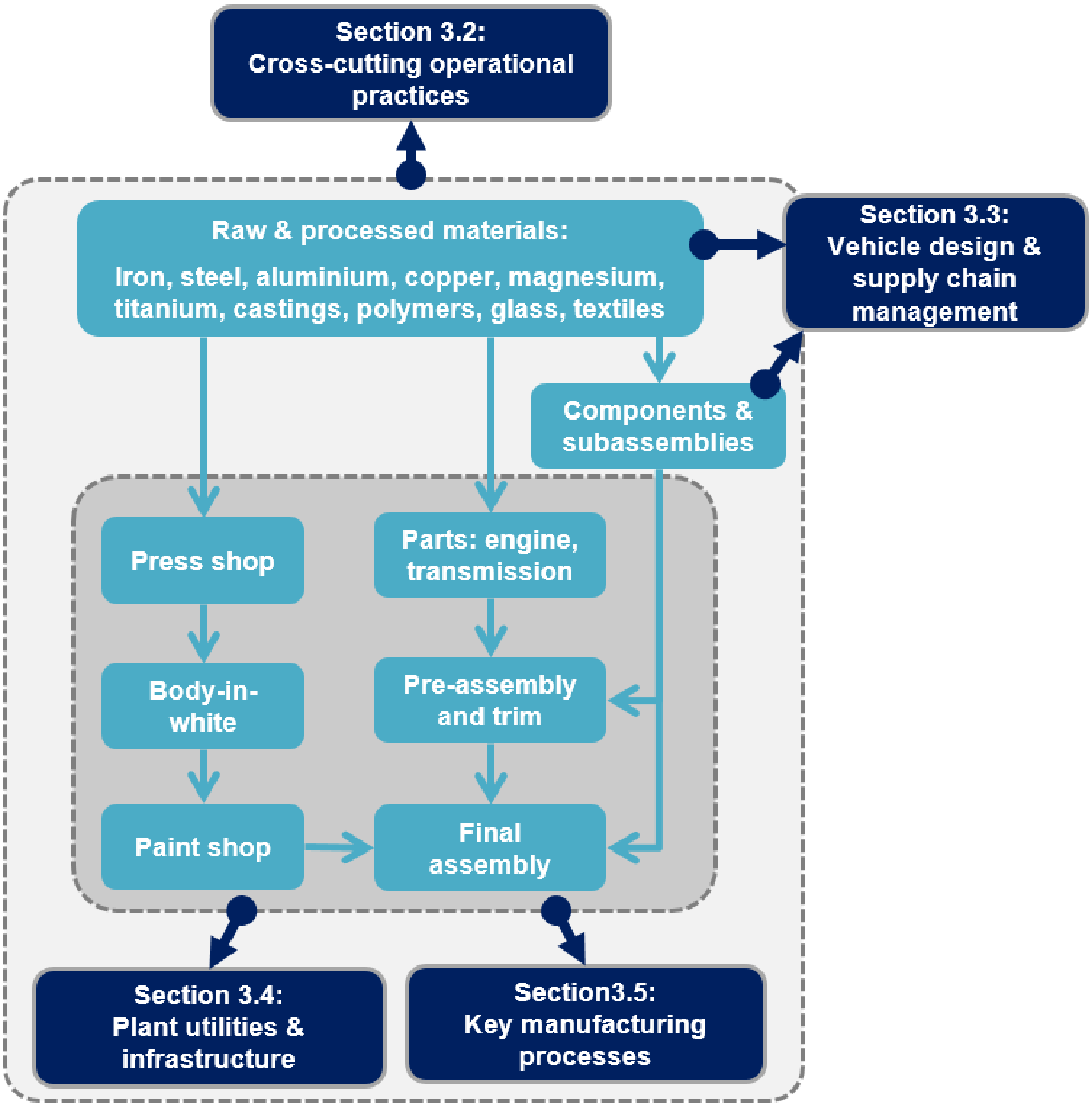
3 Best environmental management practices for the car manufacturing sector

3.1 Introduction: Chapter scope

This section describes the best environmental management practices that are relevant to car manufacturing. Figure 3-1 shows a high level overview of the topic areas covered. These span a wide range of processes due to the high complexity of vehicle design and manufacturing, as well as the trade-offs between different environmental impacts and lifecycle stages.

Figure 3-1: Overview of topic areas covered and related processes



The strategy to select the "best" environmental management practices within each topic area was based on those that achieved the greatest overall environmental improvements, as well as techniques that are considered to be enablers for improvements elsewhere (prerequisites).

3.2 Cross-cutting operational best environmental management practices

3.2.1 Section overview and technique portfolio

This chapter covers cross-cutting operational best practices that can be implemented at the organisational or site level. These BEMPs offer guidance on the design, implementation and monitoring of management frameworks for environmental issues. These frameworks are helpful in order to identify and to optimise environmental impacts across multiple processes, bearing in mind potential trade-offs between different impacts and lifecycle stages. Key actors required to ensure the best results include senior management and technical experts, as well as staff at all levels of an organisation.

BEMPs in this section cover aspects of environmental management specific to each of the main environmental impact categories relevant to car manufacturing:

- **Implementing an advanced environmental management system:** This BEMP covers environmental management systems in general, including the identification of relevant environmental impacts, effective implementation and ensuring continuous improvement. It provides guidance on how to identify the most relevant BEMPs and associated benchmarks of excellence, which is the starting point from which to realise environmental benefits associated with other BEMP techniques described throughout this document.
- **Implementing detailed energy monitoring and management systems**: This section provides further detailed guidance that is recommended for managers looking to fully optimise energy consumption. It covers key prerequisites that will be required to ensure the highest levels of performance can be achieved from advanced machinery and other manufacturing operations (see *Section 3.5: Key manufacturing processes*).
- **Waste prevention and management**: Strategies for waste management are presented in this section, with particular emphasis on "hard-to-treat" fractions. It covers best practices to eliminate waste-to-landfill and increase reuse and recycling.
- **Water use monitoring and management:** Separate guidance on water-related issues is provided in this section. This is because scientific understanding of the importance of these issues has developed much more recently compared to other areas, and as such water-related concerns are often covered less extensively in more general environmental management systems.
- **Ecosystem services review and strategies:** Similar to water, understanding of ecosystem services and their relevance has developed much more recently; hence relying on standard environmental management systems may miss some importance aspects. The concepts presented are still compatible with, and can be integrated into, more generalised environmental management systems.

The principles outlined here are often broadly applicable to many different industrial areas; therefore, significant effort has been made to tailor the guidance so that it is relevant and effective for the car manufacturing sector. In addition, these high-level BEMPs include prerequisites for implementation and/or optimisation of more process-specific BEMPs outlined in later sections.

3.2.2 Implementing an advanced environmental management system

SUMMARY OVERVIEW:				
It is considered best practice to implement an advanced environmental management system across all sites, according to a recognised certified standard such as ISO 14001 or EMAS. This enables continuous monitoring and improvement across a range of environmental factors.				
Relevant lifecycle stages				
Management	Design	Supply chain	**Manufacturing**	End-of-life
Main environmental benefits				
Energy consumption	**Resource use and waste**	Water use & consumption	**Emissions to air, water, soil**	Ecosystems & biodiversity
Environmental indicators				
• Sites with a certified advanced environmental standard (% of facilities/operations)				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	**N/A**			
Related BEMPS	• Implementing detailed energy monitoring and management systems; • Water use strategy and management • Ecosystem management reviews and strategy • Plant utilities and infrastructure • Key manufacturing processes			

3.2.2.1 Description

An environmental management system (EMS) is a tool that helps operators to develop, implement, maintain, review and monitor environmental policy. The decision to adopt an EMS is usually voluntary. However, the automotive sector currently faces increasing pressure to address environmental concerns through the improvement of internal environmental management practices – especially through EMS implementation (Comoglio & Botta, 2011).

As such, many major European and global OEM manufacturing plants use a certified environmental management system. Advanced systems are considered to be those implemented according to ISO 14001 or EMAS (EU Eco-management and audit scheme – also available as “EMAS Global”) (VCS, 2013), (EMAS Register, 2014). These are both internationally recognised systems certified by a third party. EMAS incorporates the management system requirements of ISO 14001, but has an additional emphasis on legal compliance, environmental performance and employee involvement. While a non-standardised EMS could be effective if properly designed and implemented, the use of a standardised scheme provides additional credibility.

Empirical studies of the performance of EMSs have shown that the introduction of an EMS can be expected to be at least somewhat beneficial to the environmental performance of most facilities, as well as to their operational and management efficiency and in some cases to their regulatory compliance (Commission for Environmental Cooperation, 2005), (Comoglio & Botta, 2011).

Extensive and detailed guidance on the implementation and operation of EMS is provided in other documents (see for example the European Commission EMAS website[11]) and therefore it is not elaborated in detail here.

[11] http://ec.europa.eu/environment/emas

3.2.2.2 Achieved environmental benefits

Significant short-term benefits can usually be gained following first implementation, where "low-hanging fruit" can be identified and improved. Over the longer term, an EMS can help an organisation to maintain and improve its performance level to the highest standards.

An effective EMS should lead to *continuous improvement* in management actions and environmental performance, informed by monitoring of key performance indicators. The greatest benefits will result from integration into the overall management and operation of a process, site or organisation. There are limited numbers of companies with EMSs specifically in the automotive sector, but some empirical evidence has shown that (Comoglio & Botta, 2011):

- Implementing an EMS in the automotive sector was found to increase the number of companies committed to achieving environmental improvements, as well as widening the environmental aspects involved;
- Quantification of the environmental improvements achieved in practice varies widely, but is generally positive (the mean percentages reported were highly heterogeneous, varying from 16.9% improvement in use of resources to 42.7% improvement with respect to releases to water);
- There is a direct link between the resources devoted to improvement and the improvement achieved.

A concrete example is BMW, who use a system based on ISO 14001 and the European EMAS for all production locations throughout the world, as well as all central planning departments of the production network. By integrating environmental management into all production processes, BMW were able to reduce their consumption of resources significantly as follows (BMW, 2013):

- Energy consumption: Reduced by 2.1% from 2.41 to 2.36 MWh/vehicle compared to 2012 (a reduction of 31% compared to 2006);
- Water consumption: Reduced by 1.8% from 2.22 to 2.18 m^3/vehicle compared to 2012 (a reduction of 33.1% compared to 2006);
- Process wastewater: Reduced by 7.8% from 0.51 to 0.47 m^3/vehicle compared to 2012 (a reduction of 42.7% compared to 2006);
- Waste for disposal: Reduced by 11.4% from 6.47 to 5.73 m^3/vehicle compared to 2012 (a reduction of 69.7% compared to 2006);
- VOC emissions: Reduced by 10.7% from 1.78 to 1.59 kg/vehicle compared to 2012 (a reduction of 36.7% compared to 2006).

3.2.2.3 Environmental indicators

An important indicator is to monitor uptake of EMS across the organisation as a whole – i.e. the number of sites with a certified environmental standard (% of operations).

Appropriate environmental indicators used within an EMS are measured at the process level and associated with each of the best practice techniques described subsequently in this document. Suggested indicators are based on those most commonly used in internationally-accepted standards, as well as in the car manufacturing industry, and therefore aim to reduce the administrative effort associated with monitoring. Common EMS indicators used by the automotive industry to measure environmental aspects are listed in Table 3-1 (Comoglio & Botta, 2011).

Table 3-1: Typical EMS indicators and normalisation indices used by the automotive industry

Direct Indicators	Relative factors / normalisation indices
• Fuel consumption [l or m^3] • Electricity consumption [kWh] • Annual volume [m^3] of wastewater released • Weight [kg] of recycled waste • Weight [kg] of hazardous and non-hazardous waste • Weight [kg] of produced waste, hazardous/non-hazardous waste • Concentration of TOC, dust, oily smoke, CO, CO_2, O_2 etc.	• Per number of product units • Per number of worked hours • Per number of employees • Per weight [kg] of raw materials used • Per weight [kg] of produced units

Source: (Comoglio & Botta, 2011)

3.2.2.4 Cross-media effects

When properly implemented, an EMS should address and improve the overall environmental impact of an organisation.

3.2.2.5 Operational data

According to the Association of European Automotive Manufacturers (ACEA), most (>85%) vehicle manufacturers have implemented ISO 14001 for at least some production facilities (ACEA, 2013). Frontrunner organisations have certified 100% of their facilities, and so best practice is currently moving on to implementing more ambitious targets and certifying other activities. For example, many are also extending the requirements to the supply chain, as well as service workshops/dealerships (ACEA, 2013). EMAS is often applied at the site level whereas ISO 14001 is also applied at the corporate level (ACEA, 2013).

General guidance on the implementation of EMAS is available from the official website:

- General guidance (http://ec.europa.eu/environment/emas/index_en.htm), which can be used in conjunction with the sector-specific guidance in this document.
- Organisations with non-standardised EMS can find step-by-step information on how to move to the more ambitious EMAS system in the "Step up to EMAS" study http://ec.europa.eu/environment/emas/documents/StepUp_1.htm. This provides specific information for 20 of the most commonly used EMS.
- For small and medium sized enterprises (SMEs), a simplified system – EMAS easy (http://www.emas-easy.eu/) – has been developed that allows EMAS to be implemented in a way that is proportional to the size and capabilities of smaller businesses.

However, the general guidelines provided on the implementation of EMSs allow considerable freedom in terms of the environmental criteria concerned, particularly if organisations do not have environmental managers with expertise in environmental impact assessments. Volkswagen developed a comprehensive EMS approach to be applied throughout Volkswagen's production sites. (Gernuks et al, 2006).

Box 3-1: Case study on development of EMS at Volkswagen

- Environmental issues that affect the Volkswagen brand as a whole are outlined in an environmental manual for the Volkswagen brand.
- Volkswagen documents an EMS in a specific manual for each production site, supported by an Eco Audit Team who perform environmental audits and help to prepare statements in compliance with the EMAS framework.
- In addition, a separate environmental management system according to ISO 14001 exists at Volkswagen's research and development department, dealing with product-related environmental issues.
- To determine appropriate environmental targets, a key objective is the integration of relevant production departments and their technical experts.
- For quantitative monitoring, several methods were compared in terms of being easy to understand for internal participants, having good reproducibility and being relatively quick to apply. After conducting this assessment the "Ecopoint" method[12] was selected, as it best fitted the practical needs of the company – although it was recognised that this method may not be suitable in all cases (for example, a possible limitation is that the Ecopoint method uses political targets and legal thresholds which are only partly based on scientific knowledge).
- For qualitative monitoring the "ABC" method was selected, which is based on compliance with legal thresholds. The importance of a factor is classified as:
    - A (most important) if it is higher than 80% of the legal threshold;

[12] The Ecopoint method is a simplified single-score environmental impact approach. Further information is available online at: http://www.earthshift.com/software/simapro/ecopoints97

- B if it is 50-80% of the legal threshold;
- C (least important) if it is <50% of the legal threshold.

- The quantitative and qualitative indicators help Volkswagen to identify and prioritise areas for improvement. Volkswagen annually collect environmental data from their production sites for control and communication purposes (e.g. within the EMAS' environmental statement). These data comprise emissions to air (CO_2, NOx, etc.), emissions to water (COD, N, heavy metals, etc.), and waste generation.
- Targets for improvement are developed in collaboration with several actors, including the following three key members:
  - The head and representatives of the department affected, as they know their process best and may discover potential areas of technical improvement in the process;
  - The person responsible for environmental protection of the production site, to contribute his environmental knowledge;
  - Experts in special environmental aspects (e.g. energy manager) to coordinate measures concerning this subject.
- The environmental manager of the production site compiles each department's targets and generates the environmental program for the whole production site. The environmental program is then published in Volkswagen's environmental statement.

Source: (Gernuks et al, 2006)

It may also be advantageous and cost-effective to organise environmental management globally so that best practices can be shared across all facilities, although there are challenges to achieving this including differences in culture, time zones, regulation etc. (Osborne – personal comm., 2014).

3.2.2.6 Applicability

An EMS is typically suitable for all organisations and sites. The scope and nature of the EMS may vary depending on the scale and complexity of the organisation and/or related processes, as well as the specific environmental impacts involved.

In general the most environmentally significant aspects of automotive manufacturing (i.e. the painting processes and metal-forming operations) should be prioritised and the environmental improvement options are outlined in specific policies and guidance. However, many other processes are not specifically covered by existing guidance and the scope for additional environmental improvements is still considerable.

In particular, aspects of water management and biodiversity/land contamination are generally not covered or monitored in many EMS implemented by firms in the automotive sector (Comoglio & Botta, 2011); therefore separate guidance on these aspects is provided in this report (see *Section 3.2.5: Water use strategy and management* and *Section 3.2.6: Ecosystem management reviews and strategy*).

3.2.2.7 Economics

The costs of introducing a standardised (e.g. ISO 14001 or EMAS) EMS are likely to be somewhat higher compared to non-standardised systems due to the need for verification. For smaller companies, the costs tend to be proportionally higher, and therefore a simplified EMAS system is available for SMEs. Ongoing costs are likely to be lower once the required systems are in place and staff become familiar with their obligations.

Table 3-2 provides an indication of the costs and benefits for organisations of different sizes from implementing EMAS.

Table 3-2: Costs and benefits of implementing EMAS

Organisation size	Potential annual efficiency savings (€)	Implementation costs (€)	Annual costs (€)
Micro	3,000 to 10,000	22,500	10,000
Small	20,000 to 40,000	38,000	22,000
Medium	Up to 100,000	40,000	17,000
Large	Up to 400,000	67,000	39,000

Notes: Potential annual efficiency savings are based on energy savings only, and do not include resource efficiency savings.

Source: European Commission (2013)

The costs indicated in Table 3-2 may be slightly higher compared to ISO certification costs. According to one expert, the additional efforts for the first environmental statement are around 5-20 man-days and the 3-10 man-days for updates, although the time required depends on the availability of key indicators (Schleicher, 2014). Precise costs are difficult to estimate specifically for the car manufacturing sector as many factors vary significantly, including the registration fees, day rates charged by verifiers, level of staff training etc. (Schleicher, 2014).

Most EMSs are expected to result in financial benefits due to cost savings from consuming fewer resources, producing less waste, operational efficiencies and reduced liabilities (Commission for Environmental Cooperation, 2005).

In general it is thought that larger organisations should easily be able to recover the costs of implementing EMAS (European Commission, 2013). However, the economics of an EMS are likely to be highly site-specific and the figures supplied above are indicative only (Milieu et al, 2009).

Other economic benefits that are more difficult to measure directly include (European Commission, 2013):

- Registration to EMAS or another accepted EMS can be an advantage for government procurement or business-to-business procedures, and in some cases it may be a requirement;
- EMAS-registered organisations can expect regulatory relief. There may be benefits for companies involved in manufacturing sectors, with advantages under Integrated Pollution Prevention and Control legislation;
- Improvements in corporate image.

3.2.2.8 Driving force for implementation

Implementation of an EMS can help to (European Commission, 2012):

- Address key management challenges around resource efficiency, climate protection and corporate social responsibility;
- Demonstrate compliance with legal or customer requirements;
- Provide performance measurement against set targets;
- Improve employee and stakeholder engagement in environmental protection activities.

An additional driving force for uptake of EMAS in particular is that EMAS-validated firms are often ranked differently in corporate sustainability ratings – however, to date it is mainly German production facilities that use EMAS (ACEA, 2013).

3.2.2.9 Reference organisations

Some frontrunner organisations ensure that all of their sites have an advanced certified EMS. For example:

- BMW Group use a system based on ISO 14001 and the European EMAS for all production locations throughout the world, as well as all central planning departments of the production network (BMW, 2012);
- Since 1995, the Volkswagen brand's German sites have participated in EMAS while its production sites worldwide have undergone environmental certification procedures to conform with the international standard ISO 14001 (Volkswagen, 2013);
- All General Motors (GM) manufacturing facilities have implemented the GM EMS, which is based on ISO14001 and certified according to ISO14001 or EMAS. All new GM manufacturing operations are required to implement and certify their EMS 24 months after the start of production or the date of acquisition by GM (Nunes, 2011).

3.2.2.10 Reference literature

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3.2.3 Implementing detailed energy monitoring and management systems

SUMMARY OVERVIEW:				
It is considered best practice to implement detailed energy monitoring across manufacturing sites at the process level, in conjunction with a certified energy management system in order to optimise energy consumption				
Relevant lifecycle stages				
Management	Design	Supply chain	**Manufacturing**	End-of-life
Main environmental benefits				
Energy consumption	Resource use and waste	Water use & consumption	**Emissions to air, water, soil**	Ecosystems & biodiversity
Environmental indicators				
• Number of facilities with detailed real-time energy monitoring systems (%) • Sites with a certified energy management system (% of facilities/operations)				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Implementing an advanced environmental management system;			
Related BEMPS	• Plant utilities and infrastructure • Key manufacturing processes			

3.2.3.1 Description

While automotive manufacturing facilities are relatively efficient in general, significant opportunities remain to reduce energy demand. Due to the complexity of different processes and technological variation, there are a wide range of potential options for plant-wide energy efficiency. In particular, many of these opportunities exist outside of the core energy-consuming production processes for which there is separate, specific guidance (such as paint and metal-forming operations – see *Section 3.5: Key manufacturing processes*).

An *energy* management system (EnMS) can be based on a standardised or customised form. Implementation according to an internationally accepted standard can give higher credibility to the EnMS and also open up opportunities for gaining certification against certain industry standards. The purpose is similar to that of establishing an *environmental* management system (EMS) (see *Section 3.2.2: Implementing an advanced environmental management* system), but with a clear emphasis on energy consumption. While many plants across Europe have chosen to use an environmental management system, there are additional benefits to incorporating the aspects of an EnMS as described below.

According to one plant manager, the importance of energy expended in the production of each vehicle is now seen on par with the issue of man hours per unit—the area of overriding concern just a few years ago (Holt, 2012). A plant with an output of 1,000 vehicles per day can use several hundred thousand MWh of electricity per year (Siemens, 2013). Real-time information can be exchanged between production systems, departments and production sites, potentially leading to continuous improvement of energy use in manufacturing sites.

Energy management plans and target-setting are important to allow energy efficiency to be incorporated into management activities. Plans should include the following aspects (Carbon Trust, 2013):

- **Establishing an energy strategy** involves setting out how energy will be managed. It should contain an action plan of tasks, which will initially involve understanding the organisation's current position and establishing the management framework;

- **Gaining active commitment from senior management**: without the support of senior managers, the effectiveness of the energy management plan is likely to be compromised. Clear responsibilities for energy consumption must be allocated;
- **Performance measurement:** identifying energy savings is an ongoing process which must be supported by detailed energy monitoring and analysis to determine potential opportunities for saving;
- **Staff training:** in energy efficiency and carbon reduction can help change behaviour in the workplace, to reduce unnecessary energy consumption;
- **Communication:** employee engagement and communications are an important part of developing an organisation's culture of energy efficiency;
- **Investment:** energy efficiency investments often have to compete directly against other demands for capital budgets. Budgets for energy efficiency should therefore be ring-fenced to ensure they are not diverted, and a proportion of the energy savings must be retained for further efficiency measures. Appraisal of investments should be made on a whole life-cycle basis.

Table 3-3 shows how best practice measures can be distinguished from good practice and fair practice, when considering each of the above aspects.

Table 3-3: Energy management matrix

	Best practice	Good practice	Fair practice
Energy policy, strategy and action plan	Energy policy and action plan in place and reviewed regularly, with active commitment of top management.	Formal policy but no active commitment from top management.	Un-adopted policy.
Organisational structure	Fully integrated into senior management structure with clear accountability for energy consumption.	Clear line management accountability for consumption and responsibility for improvement.	Some delegation of responsibility but line management and authority unclear.
Performance measurement	Comprehensive performance measurement against targets with effective management reporting.	Weekly performance measurement for each process, unit or building.	Monthly monitoring by fuel type.
Training	Appropriate and comprehensive staff training, tailored to identified needs.	Energy training targeted at major users following a needs assessment.	Ad-hoc internal training for selected people as required.
Communication	Extensive communication of energy issues within and outside of organisation.	Regular staff briefings, performance reporting and energy promotion.	Some use of organisational communication channels to promote energy efficiency.
Investment	Resources routinely committed to energy efficiency. Consideration of energy consumption in all procurement.	Same appraisal criteria used for energy efficiency as for other cost reduction projects.	Low or medium cost measures considered only if payback period is short.

Source: adapted from (Carbon Trust, 2013)

Organisations should aim to achieve best practice measures across all of these aspects. Without proper integration and strong communications across the organisation, energy management becomes easily marginalised and undermined. Common weaknesses that lead to poor energy management include the following issues (Carbon Trust, 2013):

- No active support from senior management;
- Lack of specific targets and commitments;
- Out-of-date documents/targets;
- EnMS is not supported by a strategy with the ability to deliver.

Target setting should be based on challenging but achievable targets that can be determined through analysis of energy data and/or benchmarking against internal or external performance.

The implementation of an EnMS should preferably be done according to formal standards that require organisational improvements, such as **ISO 50001**. ISO 50001 is a standard introduced in 2011, which specifies the requirements for establishing, implementing, maintaining and improving an EnMS. It is modelled after ISO 14001 (environmental management standard) and ISO 9001 (quality management), but differs in that it requires an organisation to demonstrate that it has improved its performance. In addition, adherence to these standards will allow energy management efforts to be officially certified and recognised.

ISO 50001 has been successfully implemented in many industries and frontrunner automotive manufacturers have already implemented it across the majority of their sites; therefore best practice is to implement more ambitious targets. For example, Fiat reports that by 2014 all of their main plants (representing more than 90% of total energy consumption) will be certified to the new standard (Fiat - personal comm., 2014).

3.2.3.2 Achieved environmental benefits

EnMSs are useful where incremental gains are being sought through process refinement and efficiency measures, without requiring radical redesigns of the process. While the energy savings brought about by each individual measure are typically small, the cumulative savings can be substantial.

Organisations with a poorer starting point may achieve more significant short-term improvements, but there are typically opportunities still available even for firms that are relatively advanced in their techniques. For example:

- Nissan Smyrna (USA) implemented an EnMS, leading to energy savings of 264,000 GJ per year (7.2% compared to 2008 levels) (Clean Energy Ministerial, 2013). This was achieved in addition to efforts in previous years to reduce energy consumption. For example, the plant had already implemented no- and low-cost measures such as turning off machinery when not in use. The savings due to the new EnMS were therefore in addition to the 11.4% saving achieved in previous years.

In such cases, an EnMS helps to ensure continuous improvement as well as maintenance of high standards.

One key application is to identify opportunities to switch off sections of the plant during non-productive times. The coordinated deactivation of power loads that are not required during long periods of production standstill - such as company vacations - can reduce the energy requirement by up to 80%. Over shorter breaks - such as lunchtimes - savings of up to 40% can be achieved (Holt, 2012). Real-world examples of implementation include:

- At the BMW engine plant in Steyr (Austria), energy demand is measured every 15 minutes at some 700 monitoring points. This detailed information was used to identify and shut down everything not in use, and enabled the plant to reduce base load energy consumption from eight to five MW (Siemens, 2013);
- Seat Martorell (Spain) implemented an EnMS from Siemens (B.Data) which monitors all energy and material flows. Energy consumption can be assigned to the respective cost units on a usage-related basis, even where complex calculation models are used (Holt, 2012). This allowed them to identify and implement significant energy savings across the plant through simple measures such as detecting leaks or allocating loads more efficiently. Without the need for additional investments, these measures resulted in energy cost savings of between 5% and 10% (Holt, 2012);

- Tracking real-time energy use for General Motor's US manufacturing sites resulted in nearly 2.5 million data points, which are monitored every minute to create real-time energy performance indicators (General Motors, 2013).

Increasing energy efficiency also provides ancillary benefits, such as greater productivity, fewer rejected parts and wastes, and reduced emissions to the environment, as well as lower energy expenditures (US DoE, 2008).

3.2.3.3 Environmental indicators

The level of implementation is a key factor and therefore indicators include:

- Number of facilities with implemented EnMSs (%);
- Number of facilities with detailed real-time energy monitoring systems (%).

Results can be monitored at the facility level in terms of energy consumption (MWh) per vehicle (at assembly plants) or per engine (at engine manufacturing plants), which are standard industry measurements.

The actual figure is dependent on the functions handled at each plant. Those with their own bodywork shops, foundries and stamping shops will clearly use more energy than simple assembly plants. Even within a single plant, a comparison over time may be difficult due to changes in utilisation or changes in the models produced. Thus, the need for detailed process-level monitoring is stressed.

3.2.3.4 Cross-media effects

Energy management should be integrated with other environmental objectives and consider the overall environmental impact (see *Section 3.2.2: Implementing an advanced environmental management* system). It should be noted that it may not be possible to both maximise the total energy efficiency and minimise other consumptions and emissions (i.e. energy may be required to reduce emissions to air, water and soil).

3.2.3.5 Operational data

Examples of specific initiatives implemented at each step are outlined below, based on Nissan Smyrna plant's joint project with the U.S. Energy Department's Advanced Manufacturing Office (AMO) to implement an EnMS (Clean Energy Ministerial, 2013) and (Roden, 2011):

- **Establishing an energy strategy**: Nissan's commitment to energy efficiency is enshrined in its corporate social responsibility objectives. The group-wide corporate Green Program aims to reduce CO_2 emissions by 20% across all Nissan manufacturing facilities by 2016 (based on tonnes of CO_2 per vehicle compared to fiscal year 2005). Nissan's Smyrna facility then developed an energy management policy (nationally applicable), set objectives for improving its energy performance, developed an energy profile for the site, and calculated its energy baseline (2008).
- **Gaining active commitment from senior management**: Nissan established a North America Energy Team to achieve corporate energy reduction goals in its U.S. region. This cross-functional team is led and supported at the executive level by Nissan's Sr. Vice President and Director/Plant Manager. The Vice Chairman for Nissan America participates in Energy Team Meetings and award ceremonies, and actively supports energy efficiency initiatives company-wide. This executive-level support has been critical to the success of Nissan's energy efficiency efforts.
- **Performance measurement:** The plant uses a sophisticated sub-metering system, which measures values every six seconds. The sub-metering system was improved and retrofitted in 2010 to better measure, calibrate, and verify energy consumption values. Plant staff analyse data several times per day and senior management review it every week.
- **Staff training:** Nissan's Energy Team attended training in statistical techniques to analyse and normalise energy data. The Energy Team provides educational materials that teach both technical and non-technical staff easy ways to conserve energy and identify energy savings

opportunities. Modelled after the company's safety awareness program, each work group has a Green Team technician who serves as an environment/energy representative

- **Communication:** Nissan implemented a data visualisation project that made the energy consumption data accessible to everyone. The monitoring data helped plant personnel to recognise their own impact on energy use. They implemented a behaviour-based sustainability approach to encourage employees to take ownership of sustainability objectives. Nissan also regularly sponsors employee Earth Day Fairs, Energy Fairs, and Family Day Fairs that provide employees and their families with access to key residential sustainability professionals.
- **Investment:** Shifting the culture and convincing plant officials to invest in energy efficiency initially posed a major challenge. Some believed the company had already seized all opportunities to reduce energy usage; however, the performance measurement data highlighted correctable, previously undetected energy losses.

3.2.3.6 Applicability

Certified EnMSs should be applicable to all plants. For example, almost all of Volkswagen's European sites have now been certified to ISO 50001 (22 sites), with other sites planned to follow over the next few years (Volkswagen, 2013).

Introducing detailed energy monitoring and management systems can be beneficial for any facility, as information from sub-metering can be used to identify measures that would not be detectable otherwise. Retrofitting of these monitoring systems is possible, and energy management plans should be implemented and continually updated.

One of the key applications is to identify the causes of plant base load – although there is little production during this time, energy consumption can account for up to 30% of the working day total (Siemens, 2013). Tracking energy consumption at a high level of detail also enables the introduction of other measures, by adapting the control software to production machinery (Siemens, 2013).

3.2.3.7 Economics

Nissan Smyrna (USA) implemented an EnMS to meet the requirements of the US Superior Energy Performance (SEP) certification (see "driving forces for implementation" below). Nissan invested $331,000 (€238,000) to implement SEP (including internal staff time) with a payback period of four months (Clean Energy Ministerial, 2013). The capital and operations projects implemented at the plant are saving Nissan around $1.2 million (€0.86 million) per year, with annual cost savings attributable solely to SEP of $938,000 (€675,000) (Clean Energy Ministerial, 2013). The plant is expected to retain the savings over time through the ongoing use of the management system.

Table 3-4: EnMS costs and savings

	Cost (€)
EnMS development and data collection	€158,000
SEP/ISO 50001 audit preparation	€22,000
External technical assistance	€32,000
Energy monitoring and metering equipment	€15,000
SEP/ISO 50001 third part audit	€12,000
Total costs	**€238,000**
Annual operational savings	**€675,000**
Marginal payback	**4 months**

Notes: Exchange rate $ to € assumed to be 0.72

Source: (Clean Energy Ministerial, 2013).

Typically payback periods are less than six months and implementation costs are low. Example one-year returns versus implementation costs at individual General Motors plants include (Sustainable Plant, 2011):

- For weld water pumps/cooling tower/fans, chilled water and exhaust fans: 700%;
- For hydraulic pumps, ovens, weld water pumps/cooling towers/fans: 400%;
- HVAC and line lighting: 500%;
- Ventilation, line lighting, air supply/exhaust: 500%.

3.2.3.8 Driving force for implementation

Several driving forces have been identified, including (Clean Energy Ministerial, 2013):

- Cost savings;
- Certification standards. For example, in the USA the SEP is a market-based plant certification programme. To be certified under SEP, an industrial plant must implement an EnMS in conformance with ISO 50001 and make verified improvements in energy performance;
- Setting an example for companies in the supply chain.

3.2.3.9 Reference organisations

BMW engine plant in Steyr, Austria (Siemens, 2013); Seat production facility in Martorell, Spain (Holt, 2012); Nissan vehicle assembly plant in Smyrna, Tennessee, USA (Clean Energy Ministerial, 2013).

3.2.3.10 Reference literature

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3.2.4 Waste prevention and management

SUMMARY OVERVIEW:				
Frontrunner organisations have implemented an overall organisational waste management strategy with high level targets for waste minimisation. This strategy is then implemented at the site level with tailored waste management plans that minimise waste production during operations and establish strategic partnerships in order to find markets for remaining waste fractions.				
Relevant lifecycle stages				
Management	Design	Supply chain	Manufacturing	End-of-life
Main environmental benefits				
Energy consumption	**Resource use and waste**	Water use & consumption	**Emissions to air, water, soil**	Ecosystems & biodiversity
Environmental indicators				
• Whether an overarching waste strategy with targets for improvements has been established and implemented • The number of sites with advanced waste management plans in place • The number of sites achieving target levels of waste management, such as zero waste to landfill				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Implementing an advanced environmental management system;			
Related BEMPS	• Integrating environmental requirements into supply chain management			

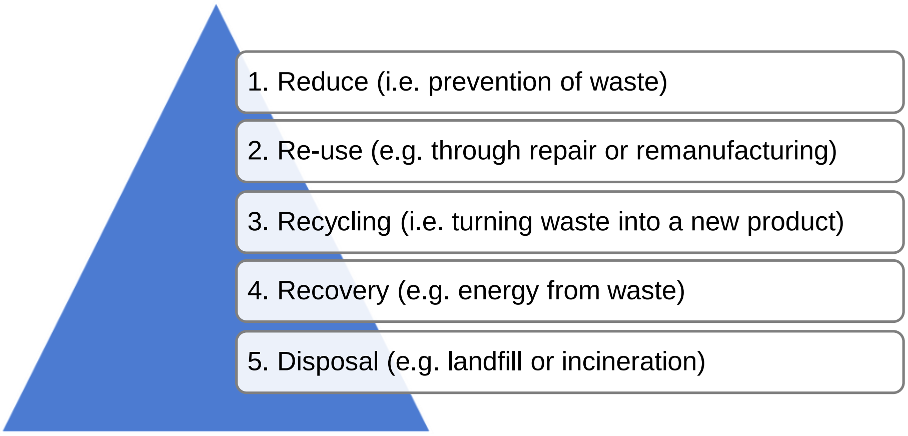
3.2.4.1 Description

The automotive industry is a resource-intensive industry, and so best practices to prevent and manage waste are important to reducing overall environmental impacts. While most other environmental impacts are concentrated in the use phase of a vehicle, the majority of solid waste (60-80%) is generated during the manufacturing stage (Oakdene Hollins, 2011).

The automotive industry has historically had an intense focus on in-process efficiency. Many waste prevention and management measures have already been implemented due to the sector's strong emphasis on lean production methods, quality control and cost-reduction. However, while these measures have been a key driver, there are certain "blind spots" from an environmental perspective (such as waste prevention, reducing hazardous materials and considering life-cycle approaches). As such, to date the automotive sector appears to have prioritised landfill diversion and materials recovery targets under the End of Life Vehicle Directive, as opposed to waste prevention measures.

The use of waste management plans is an accepted practice in many industries – the general principles should follow the *waste hierarchy*, as described in the European Waste Framework Directive (see Figure 3-2). Frontrunner organisations have implemented an overall organisational strategy with high level targets for waste minimisation, which is then tailored for specific sites through waste management plans (GM, 2013), (Farish, 2013). These strategies identify the importance of waste in terms of its impact on both environmental and economic performance.

Figure 3-2: The hierarchy of options for the treatment of waste during the manufacture of vehicles. Greatest environmental benefit is achieved at the top of the pyramid, while landfilling results in no environmental benefit.



Source: European Waste Framework Directive 2008/98/EC

Frontrunner organisations have achieved considerable progress in terms of reaching “zero waste to landfill” and moving up the waste management hierarchy to include “zero waste to landfill and zero waste to incineration”.

Despite this, some statistics show that waste generation in automotive manufacturing has increased – due to a combination of increasing vehicle mass and/or due to the fact that some principles of **waste minimisation/avoidance** that do not relate directly to lean production or customer satisfaction (Oakdene Hollins, 2011). Several manufacturers still send a significant proportion of their overall waste to landfill.

Overall, this suggests that there could be significant potential to improve waste management practices in the automotive industry, particularly around increasing the focus on waste prevention. This section provides additional details on aspects that are specific to wastes generated during the manufacture of cars.

3.2.4.2 Achieved environmental benefits

Increasing material recovery and reuse can help to reduce the demand for raw materials, as well as the volume of waste delivered to landfill.

Many automotive manufacturing sites have achieved zero waste-to-landfill (meaning that 100% of waste is diverted from landfill). Toyota, GM and Daimler all have stated their intentions to achieve this goal across their sites. For example, GM reported that in 2012, just over half of its worldwide facilities (total count of 83 manufacturing sites and 19 non-manufacturing sites) are now landfill-free, and on average, 97% of the waste generated from everyday manufacturing operations at these plants is recycled or reused, and 3% is converted to energy (GM, 2012).

Some more advanced best practice sites have managed to exceed this level of environmental achievement, reaching 100% diversion of waste from both landfill and incineration. For example, Toyota’s TMUK plant (UK).

3.2.4.3 Environmental indicators

Appropriate indicators of the level of implementation are:

- Whether an overarching waste strategy with targets for improvements has been established and implemented; and
- The number of sites with advanced waste management plans in place.

In terms of environmental achievements, the following indicators are used as standard in the automotive industry:

- Total waste per unit (kg/vehicle);
- Hazardous waste per unit (kg/vehicle); and
- Waste sent to various streams, including recycling, energy recovery and landfill (kg/vehicle, % total waste). For example, at the Rolls-Royce plant in Goodwood (UK), no non-recyclable waste was produced in 2013 (BMW, 2013).

These should be reported at the organisational level, but should also be monitored per site – for example, all GM plants monitor, measure and centrally report their performance on a monthly basis where it is evaluated against company-wide waste-reduction goals (GM, 2012). Best practice would be to set targets and monitor waste at the process level. For example, at Toyota, each shop has its own waste target (Toyota - personal comm., 2014).

An optional indicator is to monitor the **level of non-saleable waste** (Atkinson, 2012). Although this indicator is vulnerable to changes in the price for recycled materials, the market conditions are an important determinant of the potential for reaching waste reduction targets in the most economical way. For example, Toyota use this indicator to ensure that their waste reduction plans are economical - they have reportedly reduced their non-saleable waste by 50% in five years from 40 kg per vehicle to 18.1 kg per vehicle, and aim to reduce this to zero in the future by finding additional viable markets for their waste streams (Atkinson, 2012).

3.2.4.4 Cross-media effects

In some cases, a greater volume of segregated recyclate/waste streams could increase other environmental impacts, for example:

- A strong emphasis on achieving "zero waste to landfill" may detract from the more fundamental activity of waste prevention (Oakdene Hollins, 2011);
- Increased energy use and fuel consumption in the waste collection/logistics chain. These environmental impacts could be reduced through the use of local waste treatment, as well as optimisation of logistics chains; and
- Increased energy usage may be required in order to reduce waste (Atkinson, 2012). For example, the use of different processes and/or materials may lead to trade-offs between energy usage and waste. Reuse of old machinery may have trade-offs in terms of the energy efficiency that can be achieved.

Because of these trade-offs, decisions should be considered from a life-cycle perspective (see *Section 3.3.2: Design for sustainability using Life Cycle Analysis (LCA)).*

3.2.4.5 Operational data

Option 1 – Reduce

The first priority in waste management is the prevention or reduction of waste arisings, through forward planning, improved methods of manufacturing, and the management of supply chain waste. Particular attention should be given to prevention of waste that will subsequently be difficult to reuse, recycle or recover (including hazardous waste).

Examples of recent waste reduction techniques used in the automotive sector are shown in Table 3-5.

Table 3-5: Case study examples: waste reduction techniques used in the automotive sector

Waste stream	Example	References
Reducing paint sealer waste	Excess paint sealer is considered a hazardous waste if disposed. The Toyota Cambridge plant installed an automated system in 2012 to capture excess sealer and reapply it to a vehicle without impacting the quality of the paint finish. A reclaim pump system was installed with a valve to control when the reclaimed sealer is used. The reclaimed sealer is only applied on non-visible seams in the inner shell of the vehicle. The system has reduced the volume of virgin sealer ending up as waste by 97% and eliminated 72 barrels of hazardous waste per year - more than 22,000 kilograms – with a payback of less than two months. The system is now being transferred to other plants.	**Toyota, Cambridge (US)** (Toyota, 2013)
Paint sludge	The quantity of paint sludge discharges has been reduced through filtration methods, an action which has resulted in a 20%-30% reduction in sludge, while also generated financial gains. In addition (cross-referenced with recycling activities), Renault has collaborated with a private company (Soliforte), to reprocess paint sludge into cement bricks. Approximately 62 tonnes of paint sludge is used in this process.	**Renault, Flins (France)** (Renault, n.d.) **Renault, Campo Largo (Brazil)** (Renault Brazil, 2013)
General packaging	Many examples involve the introduction of reusable packaging of supplied materials: • 23,000 tonnes of packaging waste saved by Ford (UK) through developing a system of returnable packaging • 3,000 tonnes of waste avoided annually by Toyota (US) through switching to returnable packaging for carpets; • At Honda UK, 99% of local suppliers are now using returnable packaging as standard, some of which have a service life of over 7 years.	**Ford (UK) and Toyota (US)** (Oakdene Hollins, 2011); **Honda, (UK)**(Honda, 2011)
Improving material yield from metal-forming operations	In 2012, Volkswagen reduced the width of steel coils used to make parts for the body, at their Wolfsburg site. Additionally, the tools, the component geometries and plates nesting were optimised to improve materials utilisation. The new Golf generates 15% less waste during production than its predecessor.	**Volkswagen, Wolfsburg (Germany)** (Volkswagen, n.d.)
Reducing hazardous waste	• Used liquid flux instead of using powder flux and purchased ready-coated flux materials reduced hazardous waste by 22% in the first year at Denso (UK) • 68 tonnes of waste (55 tonnes of which hazardous) prevented annually by switching from cleaning with methylene chloride to blasting with baking soda (Trimac Transportation) • Switched from single use to washable/reusable wipes for machinery cleaning reduced hazardous waste costs by £5,000 at Denso (UK);	(Oakdene Hollins, 2011);

Option 2 – Reuse

Reuse refers to the reuse of materials in their current form, prolonging the product's life before it becomes waste. Examples of waste reuse techniques used in the automotive sector are shown in Table 3-6.

Table 3-6: Case study examples: reuse of waste materials in the automotive sector

Waste stream	Example	References
Coolants	US company, Universal Separators has a system called SmartSkim that can continually recycle and re-use the coolant fluid used to lubricate and control the temperature of machining operations at the point where a cutting tool comes into contact with a metal workpiece. The tool is used by OEMs including Delphi, Nissan, Honda and Toyota. The benefits of the system include a reduction in coolant consumption of between 30-75%. The cost savings can be as much as 90%. An investment of $15,000-45,000 (€11,500-35,000) could pay for itself within 12-18 months.	**Delphi, Nissan, Honda and Toyota** (Farish, 2013)
General packaging	Cadillac Urban Garden contains 250 plant beds made from redundant shipping crates donated from GM's nearby Orion assembly plant for direct use in the community project, rather than being scrapped or recycled.	**GM, Orion plan in Detroit (US)** (Farish, 2013)
Metals	Metals from stamping and powertrain operations are valuable, especially considering the amount generated on a manufacturing line. Large cutouts like window openings are usually sold on to third parties to make another product, or used within the plant in one-shot presses to make smaller body in white components. The metal grindings and scraps that GM does not re-melt or reuse are sold to third parties such as foundries.	**GM (US)** (General Motors, n.d.)

In addition to the reuse of materials, new plants being built in low-cost countries may be able to benefit from installing previously-used manufacturing equipment, such as (Duval Smith, 2011):

- **Conveyors.** The "FAStplant" modular final assembly system from Dürr can be moved easily if the company changes manufacturing location. Daimler, the first FAStplant customer, went on to relocate its system three times within a period of six years – the setup is currently being used in its fourth location;
- **Paintshops.** Tata Motors installed a previously used paintshop in their Pune plant (India). Engineers collected the paintshop from Nissan (Australia), shipped it to India, then reconditioned it for installation. It was a cost-effective solution and expanded plant capacity from 500 to 750 units per day;
- **Presses.** The market for used standard presses is established, but for large or special presses the market is limited. If the mechanical structure is reliable and there is no major damage or any cracks, the cost for a complete refurbishment is between 30 and 50% of the sale price.

There is also an established industry for robot repair, which optimises maintenance schedules and therefore extends machine lifetimes. For example, Fiat's Tychy plant (Poland), use Comau Robotics with 'stress analysis' software, which helped Fiat to reduce mechanical breakdowns to zero, whereas in 2007, Fiat had at least 20 breakdowns a year caused by robots (Duval Smith, 2011).

Option 3 – Recycle

Recycling refers to a recovery operation in which waste materials are reprocessed into products, materials or substances (whether for the original or other purposes).

Best practices for implementing recycling include:

- **Collection and segregation:** techniques established and implemented throughout the business;
- **Measurement and monitoring** of waste generation and provision of resources for its management;

- **Procedures and methodologies** ensure best management options for manufacturing waste;
- **Provision of waste logistics** allows waste to be moved efficiently to the most appropriate treatment process;
- **Partnerships and stakeholder engagement** can be used to foster market conditions that strengthen the market for recycled materials by encouraging a recycling-based society (e.g. by teaching school children about recycling).

One of the most challenging aspects is often to change staff mind-set and habits. This aspect can be tackled through refresher training sessions and support from on-site Environmental Teams, as has been implemented by Gestamp at their Chattanooga site (Stillwell, 2014). Further examples of successful approaches used by Toyota are outlined in Box 3-2.

Box 3-2: Case study on recycling management at Toyota (France) (Toyota - personal comm., 2014)

Toyota's TMMF plant, near Valenciennes reduced waste per vehicle by 39% between 2001 – 2013, achieving zero waste to incineration (without energy recovery) in 2007.

Collection and segregation. At TMMF, 126 categories of material are segregated on the factory line. Each process on the factory floor has specific wastes that are allocated a specific bin. Colour coding, transparent containers and picture labelling is used to make identification easier. Indeed, making recycling intuitive for busy employees has been a key principle, even where this has resulted in separating parts to a greater degree than is necessary such as placing red parts into a red bin, regardless of whether they can be recycled together with different-coloured parts of the same material. Recycling bins are then sorted by trained staff. Accurate sorting has allowed TMMF to eliminate emissions associated with processes at segregation and pre-treatment centres, as well as transport between these sites. The sorting methods employed are estimated to cost around €500/year.

Measurement and monitoring is also a key tool to ensure continuous improvements.

- Internal waste audits are conducted every day, week and month.
- Waste segregation on each line is monitored at the end of each shift, so that individuals who repeatedly put waste in the wrong bin can be provided with further training.
- Every individual bag of waste is audited for quality before being removed from the plant. However, not all waste streams need to be checked with the same stringency (e.g. plastics need to be checked more thoroughly than metals).

Optimised logistics can reduce fleet emissions and minimise loss of stock. For example, baling of paper and cardboard has reduced collections significantly, by allowing greater density of packing. Minimal storage on site reduces potential damage or loss of stock.

Partnerships are critical to creating a recycling-based market. TMMF works with Green Metals, a waste management firm, to identify potential markets for all materials.

Examples of waste recycling techniques used in the automotive sector are shown in Table 3-7.

Table 3-7: Case study examples: recycling of waste materials in the automotive sector

Material	Example	Manufacturer & site
Plastics	Bumpers are injected on-site, rather than at a supplier's plant. This means closed-loop recycling of scrap is achieved at the plant. The plastic is ground, re-melted and incorporated into parts.	**Toyota, Valenciennes** **(France)** (Toyota - personal comm., 2014)
Electronics	At Toyota's Valenciennes plant, electronic waste is completely dismantled on-site to achieve greater financial value from sale of the materials (e.g. copper and aluminium).	**Toyota, Valenciennes** **(France)** (Toyota - personal comm., 2014).

Material	Example	Manufacturer & site
General packaging	Cardboard shipping materials from the GM Marion Stamping and Fort Wayne Assembly plants are recycled into sound-absorber material in the Buick Lacrosse's headliner. Plastic caps and shipping aids from the Fort Wayne facility are converted into radiator shrouds for the Chevrolet Silverado and GMC Sierra pickups built at the plant	**GM, Marion Stamping and Fort Wayne (US)** (General Motors, n.d.)
Tungsten	Tungsten is a scarce metal used in dies and cemented carbide tools in car manufacturing. Until recently ~60% of cemented carbide product scrap was shipped overseas and ~10% discarded, only 20% was recycled. Through collaboration with a cemented carbide recycling company, Toyota established a recycling system able to recover tungsten from cemented carbide product scrap in 2010. An optimum recycling system was built for each product type, which also improved the economic viability of recycling by reducing the amount of sorting required.	**Toyota (Japan)** (Toyota, 2013)
Aluminium	Aluminium swarf contaminated with machining coolant that was previously transported off-site for recycling is now recycled . • Stage 1 was to reduce the coolant contamination by utilising a centrifugal coolant recycling system to wash and dry the contaminated swarf. This also recovered 10% of coolant waste. • Stage 2 was to re-melt the dry swarf safely in their own furnaces. Toyota used heat recovered from the furnace exhaust to dry the swarf before melting. Aluminium yield increased from 70% to 93% exceeding the reducing aluminium deliveries by 10%, and reprocessing costs by 40%.	**Toyota (UK)** (SMMT, 2013)
Carbon fibre	Scraps left over from the production of Carbon Fibre Reinforced Plastic (CFRP) components can be returned to the production process.	**BMW, Leipzig (Germany)** (BMW, 2013)
Foundry sand	A new system for the regeneration of foundry sand was launched. This system makes it possible to recover, and bring back into the production cycle, a portion of the sand used to mould cores, thus obtaining a reduction in the amount of hazardous waste generated, and the consumption of new sand. The construction of a sand regeneration system using the same technology has started at the Teksid Hierro de Mexico di Monclova plant. Representing an investment of approximately €4.5 million, the system will be operational in the last quarter of 2013 and will be able to recover up to 10 tons of sand per hour.	**FIAT, Teksid in Ingrandes sur Vienne (France) & Teksid Hierro de Mexico di Monclova (Mexico)** (FIAT, 2012)
Organic waste	Toyota's Georgetown, Kentucky, plant has 7,000 employees and seven cafeterias. All of the organic waste from the cafeterias, including the oils and greases, as well as the paper and other waste from the offices, is composted.	**Toyota, Georgetown (US)** (Atkinson, 2012)

Material	Example	Manufacturer & site
Paper	Toyota's plant in Indiana installed a paper pulper in 2009 to recycle paper products from the cafeteria. In 2010, it expanded the recycling program to paper products from the plant's bathrooms and break rooms. The pulper shreds the paper products and mixes them with water to form a slurry. Most of the water is then removed and reused by the pulper. The pulp is then sold to a paper recycling facility to make paperboard and cardboard boxes. In the past three years, almost 227,000kg of paper have gone through the pulper.	**Toyota, Indiana (US)** (Atkinson, 2012)
Coolants	GM, Daimler and Chrysler (US) have been using waste management specialist Preferred Filter Recycling (PFR) to achieve complete 'cradle-to-cradle' re-use of filter media used to capture machining coolants, 'wet' and 'dry' paint materials, floor spills and airborne contaminants generated during manufacturing operations. A six-stage heat-based process reduces them, and the residual contaminants they contain, into resins that can be moulded into new products. Critically, the polypropylene filters, infused with otherwise vexatious wet paint sludge, produce a robust resin that can be used to make industrial-grade pallets which enable the re-use of the sludge. The process offers clients distinct cost savings in the range "5-10%" over alternative waste disposal methodologies.	**GM, Daimler and Chrysler (US)** (Farish, 2013)

Option 4 - Recover

If the waste generated cannot be reused or recycled, it should be disposed of using technologies with minimal environmental impact, for example:

- **Waste-to-energy conversion** is the process of generating energy in the form of electricity and/or heat from direct combustion of waste, or fuel from the treatment of waste. Emerging techniques include (Farish, 2013):
  - **Plasma gasification** - turning various materials, including cardboard and sludges, into syngas.
  - **Microwaves** – a means of dealing with materials containing organic compounds, such as foundry sand, using a lower energy consumption than present methods.

Illustrative case study examples of the environmental achievements at automotive plants are described in Table 3-8. For more detailed information on waste-to-energy conversion best practice, please see the forthcoming guidance on **Best Available Techniques (BAT) reference document (BREF) on waste treatment industries,** expected to be available online[13]**.**

Table 3-8: Case study examples of waste recovery by automotive plants

Material	Example	Manufacturer & site
Used oils and evaporation concentrates	Renault supply waste oils and evaporation concentrates from powertrain plants as a replacement for fossil fuels (such as petrol coke, coal, fuel oil) in cement kilns. The high temperature cement production process can fixate almost all of the heavy metals contained in the waste.	**Renault,** (Renault, n.d.)

[13] http://eippcb.jrc.ec.europa.eu/reference/

Material	Example	Manufacturer & site
Paint sludge	Paint sludge filter cakes are dried in a condenser, and the water is recovered from a condenser (~800l/day). Paint sludge cakes are used as a substitute fuel in cement kilns, due to their high calorific value. At Toyota's plant in Valenciennes, ~50% of all plant waste comes from wastewater treatment, around half of which is from the paint shop. F	**Toyota, Valenciennes** **(France)** (Toyota - personal comm., 2014)

3.2.4.6 Applicability

Limited local recycling infrastructure and waste disposal regulations in certain regions can be a barrier to diverting waste from landfill – in these cases, working with local stakeholders is an important aspect of the waste management plan (GM, 2013).

The choice of the most appropriate waste treatment option involves consideration of logistics as well as material properties. For example, a global supply chain could incur logistical costs that will discourage the re-use of transport media (e.g. pallets) and instead create a need for recycling. In contrast, a local supply infrastructure will be more suitable for a 'return and re-use' policy that will help to avoid the need for waste management.

SMEs may not be able to afford the capital cost of some waste reduction techniques which can require new equipment, training or software. Business support is expected to be very beneficial 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 as such from one company to another (Oakdene Hollins, 2011).

3.2.4.7 Economics

Direct cost and benefit information is difficult to present, as it is highly dependent on specific business operations and approaches. General Motors report that their initial investments were $10 (€7.5) for every tonne of waste reduced, but that investment costs have decreased over time – programme costs have since been reduced by 93% and total waste has been reduced by 62% (GM, 2012). Fiat report that projects across their plants have reduced generated waste by 2.5% over 2012-2013 and have led to overall savings of around €4.5 million in 2013 (Fiat - personal comm., 2014).

- **Waste prevention:** The main cost saving achieved from waste prevention are due to less raw material being purchased and reduction in re-work costs. Avoidance of disposal costs (such as Landfill Tax or incineration costs for hazardous wastes) are an additional incentive (Oakdene Hollins, 2011).
- **Recycling and reuse**: Although revenues from recycling will vary from year to year depending on market conditions, they can generally offset the upfront costs and make recycling activities economical. For example, GM estimated its annual by-product recycling and reuse revenue at about $1 billion (€0.8 billion[14]) per year in 2012 (GM, 2012).

Better management of waste is expected to lead to better resource and risk management, thereby increasing revenue, saving costs, boosting asset values and potentially share prices. Specific costs that should be considered, include:

- The offset of landfill tax and compliance with hazardous waste regulations;
- Raw material use reduction;
- Waste logistics;
- Internal training;
- New equipment.

All costs should be considered with regards to their payback period which will be business and plant specific.

[14] Converted using average exchange rate for 2012: http://www.irs.gov/Individuals/International-Taxpayers/Yearly-Average-Currency-Exchange-Rates

3.2.4.8 Driving force for implementation

The key driving forces for optimal waste management within the automotive industry are the need to:

- Address key management challenges around resource scarcity (Toyota, 2013).
- Generate revenue from waste streams and mitigate rising waste management/landfill costs (GM, 2013) (Brown, 2008);
- Demonstrate compliance with legal or customer requirements;
- Improve employee and stakeholder engagement in environmental protection activities (Toyota, 2013);
- Improving corporate image (Brown, 2008).

Policy drivers to reduce waste include:

- **The Waste Framework Directive** to ascend the waste hierarchy.
- **Registration, Evaluation, Authorisation and restriction of Chemicals (REACH)** to avoid negative impacts from regulatory interruption to supply.
- **Restrictions on hazardous waste:** Minimising hazardous waste in painting and cleaning activities has been a key focus due to regulatory pressure (both environmental and workplace health and safety)

3.2.4.9 Emerging techniques

An example of an emerging technology is near net shape manufacturing, which aims to produce components that are close to the finished size and shape, requiring a minimal amount of finishing process (e.g. machining). Example processes include closed die forging, investment casting, metal injection moulding and more recently additive layer manufacturing (ALM). Various materials can be processed in this way including metals, ceramics and polymers. This allows a reduction in the number of processing steps, as well as waste material. These techniques are already being used in the motorsport industry, for weight critical components with high temperature requirements, but are yet to be developed for use in high volume production (Mercury Centre, n.d.).

The emergence of new vehicle technologies (particularly hybrid and electric vehicles) will offer different challenges in all life phases of vehicles. Waste prevention and management opportunities may be radically different.

3.2.4.10 Reference organisations

Examples of best practice used in this section have been sourced from Toyota, GM, Renault, Delphi, Nissan, Honda, Fiat.

3.2.4.11 Reference literature

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3.2.5 Water use strategy and management

SUMMARY OVERVIEW:				
Water management is an issue of increasing concern that is typically not covered in detail in standard environmental management systems. Therefore it is best practice to implement monitoring and to conduct a review of water management issues according to a recognised tool such as the CEO Water Mandate.				
Relevant lifecycle stages				
Management	Design	**Supply chain**	**Manufacturing**	End-of-life
Main environmental benefits				
Energy consumption	Resource use and waste	**Water use & consumption**	Emissions to air, water, soil	Ecosystems & biodiversity
Environmental indicators				
• Sites that have conducted a water strategy review (% of facilities/operations) • Sites that have monitoring for water consumption and use (%) • Sites that have separate water monitoring for production processes and sanitary use (%)				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Implementing an advanced environmental management system;			
Related BEMPS	• Water recycling and rainwater harvesting • Water-saving opportunities in automotive plants • Ecosystem management reviews and strategy			

3.2.5.1 Description

For most environmental categories, the use phase of a car accounts for the largest share of lifecycle impacts. However, in the case of water the use phase is relatively insignificant - most water is consumed at earlier stages in the life-cycle. Even so, the major impacts typically occur in the supply chain rather than at the manufacturing facility, and thus a high level of importance is attached to conducting reviews of water across the entire value chain as well as at the plant level.

Although monitoring and benchmarking should be carried out as part of a complete Environmental Management System (see *Section 3.2.2: Implementing an advanced environmental management* system), water use is typically not accounted for comprehensively within standard EMSs (Comoglio & Botta, 2011). To help organisations address this aspect, additional guidance is provided in this section.

A large number of voluntary frameworks for water management exist, and it can therefore be challenging to keep track of developments (see the section on “reference organisations” for a list of voluntary initiatives and manufacturers using them). For convenience, this document presents a consolidated framework for water management as outlined in Figure 3-3. This broadly follows the United Nations Global Compact CEO Water Mandate, which is one of the more comprehensive frameworks, and draws in specific guidance from other voluntary initiatives where they add additional dimensions.

Figure 3-3 Water management framework

Source: (The CEO Water Mandate, 2014)

A brief outline of each stage is provided below:

1. **Assess water usage and discharge:** By quantifying water use and consumption, as well as wastewater arisings by process or department, the site or organisation can begin to identify the key water using activities;
2. **Assess risks in local watershed and supply chain:** Risks depend on the nature of efficiency of water use, potential pollution from operations and the local conditions (hydrologic, environmental, social and political);
3. **Create a plan on how to use water more efficiently and improve wastewater:** Develop an action plan in agreement with senior management to determine steps to improve water management, responsibilities and timescales;
4. **Collaboration with your supply chain and other organisations:** Companies can have a direct impact on water management in their own business, as well as an indirect impact by encouraging and facilitating actions by others;
5. **Hold yourselves and others accountable:** actions will only be sustainable and efficient if governments, businesses, civil society and other stakeholders work together;
6. **Communicate results:** Adequately report water management while minimising administrative burdens. Such reporting increases corporate accountability for their actions and better allows stakeholders to inform and guide company practices.

For further details, please refer to (The CEO Water Mandate, 2014).

3.2.5.2 Achieved environmental benefits

By better understanding how water is used, organisations can benefit from reductions in water use and improved water and effluent management. There are a range of water minimisation techniques and solutions that have been applied and proven effective at the plant level – see *Section 3.5: Key manufacturing processes*. For example, Fiat report that they have saved 2.1 billion m^3 of water in 2013 across their production plants (Fiat - personal comm., 2014).

3.2.5.3 Environmental indicators

A key indicator at the site and process level is the implementation of detailed water use and consumption monitoring (Comoglio & Botta, 2011):

- Sites that have monitoring for water consumption and use (%);
- Sites that have separate water monitoring for production processes and sanitary use (%).
- Amount of water that is internally recycled (%).

Organisations should aim to monitor the relevant indicators outlined at least at the plant level. More detailed monitoring at the process level may be implemented for the most water-intensive processes but it is unlikely to be needed for all processes.

A range of more detailed environmental indicators can be derived from the European Water Stewardship Standard (European Water Partnership, 2012). Other tools may be combined with the water footprint assessment for more extensive and complementary assessments – for more information see (ISO, 2014 [Draft]).

3.2.5.4 Cross-media effects

When implementing a water management programme, it is important to consider the wider impacts. The reduction in water volumes can cause an increase in the concentration of pollutants in the remaining effluent and a corresponding decrease in the quality of discharge water, unless compensation measures are taken. This may affect the treatment required to meet the requirements for discharge quality.

3.2.5.5 Operational data

This section provides more detailed operational information for each of the steps in the framework outlined above.

Step 1: Assess water usage and discharge

The water footprint of a product is the volume of freshwater used to produce the product, measured over the full supply chain. It is a multidimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution.

A best practice water footprint assessment should be carried out according to an internationally-recognised standard. **ISO 14046** is an extension of ISO 14001 aiming to provide specific guidance on water use. At the time of writing it is currently still in development[15], but is expected to provide a consistent assessment framework that will give water footprint results credibility (BSI, 2014).

It is recommended to include direct and indirect water use/consumption in the analysis for sites and for portions of the supply chain that are the most water-intensive. At the site/facility level, detailed monitoring systems are necessary to gain an accurate understanding - where possible, automatic meter readings should be used to reduce measurement errors. Software can be used to track water use against set indicators, and alarms should be raised if measurements fall outside of set ranges (WRAP Rippleffect, 2014). For example, Ford uses various software packages to track water use at each facility and generates monthly reports identifying successes and potential areas for improvement (Ford, 2012).

Step 2: Assess risks in local watershed and the supply chain

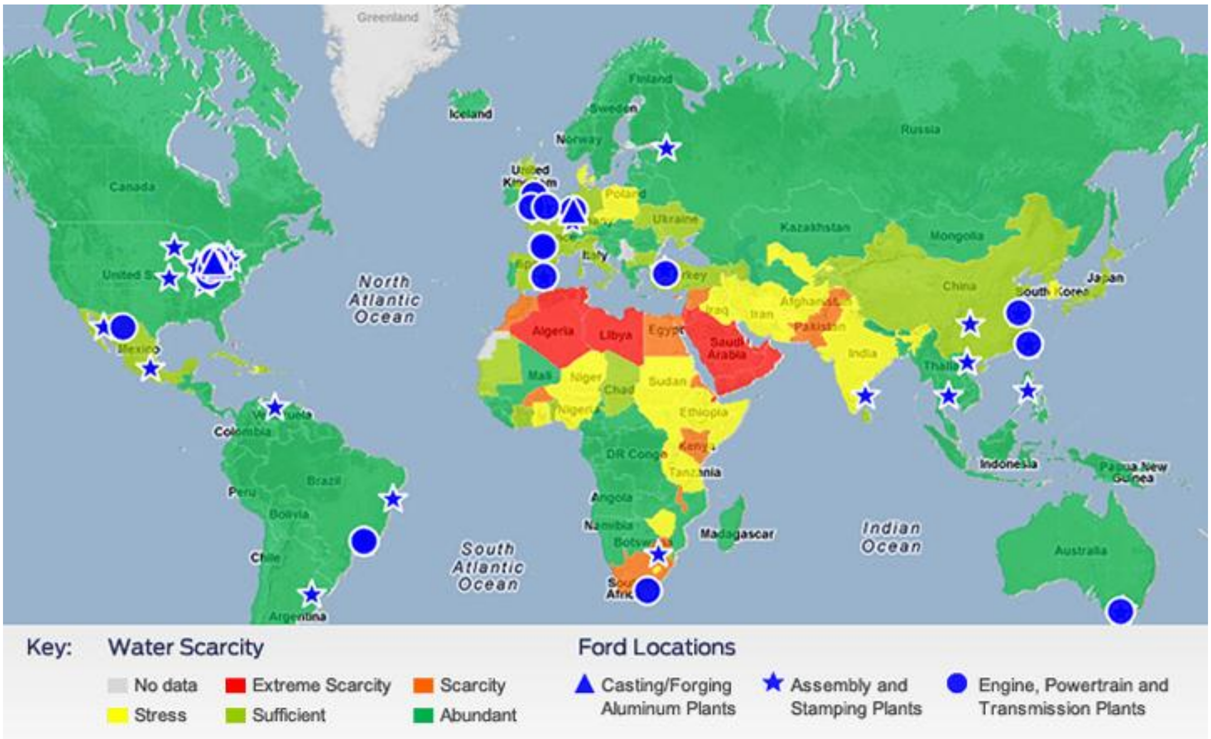
The results of water footprinting will provide a better understanding of absolute volumetric needs. Ultimately, this information should be taken in context with other environmental impacts, as a water assessment by itself cannot provide a comprehensive solution. The information should therefore be used to assess the magnitude of potential environmental impact(s) related to water, as well as opportunities to reduce water related potential risks and impacts (ISO, 2014 [Draft]).

[15] Guidance on water footprint methodologies is provided by the Alliance for Water Stewardship (http://www.allianceforwaterstewardship.org/) and the Water Footprint Network (http://www.waterfootprint.org/?page=files/home)

Automotive manufacturing is characterised by complex international supply chains and inputs from many different global regions. As such, local factors will play a role in determining and prioritising the water and effluent management actions that can be taken.

Free tools are available to support this analysis. For example The Global Water Tool is provided by the World Council on Sustainable Business Development (WBCSD, 2007). This allows organisations to map their water use and assess risks relative to their global operations and supply chains. Ford has used this tool to evaluate which of their operations are projected to be in water-scarce regions by 2025 – see Figure 3-4 (Ford, 2012). According to the analysis, approximately a quarter of Ford's operations are projected to be in such regions. The location of the most water-stressed regions is outside of Europe, highlighting the importance of taking the supply chain into account.

Figure 3-4: Results from the Global Water Tool



Source: (Ford, 2012).

The WBCSD Global Water Tool does not provide specific guidance on local situations. This requires more in-depth systematic analysis at the plant level. Companies can employ the Global Water Tool to identify and prioritise high risk sites in their portfolios. Companies can then employ the **Global Environmental Management Initiative (GEMI) Local Water Tool™** (GEMI, 2014) to further evaluate the high risk locations and identify actions to manage the risks. This is another free tool for companies and organisations to evaluate external impacts, business risks, opportunities and management plans related to water use and discharge at a specific site or operation.

Step 3: Create a plan on how to use water more efficiently and improve wastewater

A comprehensive strategy development can include many dimensions, such as establishing corporate governance and accountability mechanisms, setting goals, and defining water management philosophy (The CEO Water Mandate, 2012)**.** This must be combined with continuous monitoring and improvement to ensure that improvements are sustained.

Ambitious targets for water pollutant levels are also necessary to ensure that reductions in water volumes do not lead to reductions in water quality. Best practice organisations should aim to exceed the minimum legal requirements. For example, analysis conducted on water discharged from Fiat Group plants worldwide in 2013 revealed levels of Chemical Oxygen Demand (COD) up to 80% below regulatory requirements, while levels of Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) were up to 97% and 91% below required limits, respectively. Each plant aims to maintain this performance in 2014 (Fiat, 2012).

Step 4: Collaboration with the supply chain

In recent years more and more businesses have focused on issues and activities along their supply chains – recognising that many impacts are beyond their direct control. The degree of water use in the supply chain can be reduced by encouraging and facilitating actions with suppliers (see also *Section 3.3.3: Integrating environmental requirements into supply chain management).* To fully understand and address its external impact, a company must look outside the factory and have a firm understanding of the context in which it operates, including water stress, flooding, poor ambient water quality, regulatory uncertainty, and other factors. Local stakeholders, government and community organisations can also play a role in helping to protect and manage the area watershed (The CEO Water Mandate, 2012)**.**

Step 5: Hold yourselves and others accountable

A company with the most advanced water management practices should look to engage externally to ensure long-term business continuity by contributing to the sustainable management of shared water resources on which the company relies (The CEO Water Mandate, 2012)**.** This requires engagement among water users and other interest groups. Any deficiencies in the water governance, management, or infrastructure that allow water scarcity or conflict to emerge can create a risk to organisations. For example, Ford has been collaborating with a range of organisations such as UN Global Compact, the US State Department and the Global Water Challenge – to gain a better appreciation of outside stakeholder perspectives (Ford, 2012).

Step 6: Communicate results

Current practice in corporate water disclosure (even among the most robust reporters) typically does not adequately capture the complex and location-specific nature of water resources. CEO Water Mandate’s Corporate Water Disclosure Guidelines offer a common approach to disclosure (The CEO Water Mandate, 2012)**.**

3.2.5.6 Applicability

The importance of water as a resource has become a prominent issue in light of increasing water scarcity (BSI, 2014). Water management is a highly localised issue – that is, the same level of water consumption could put extreme strain on the available water resources in water-scarce regions, while presenting no issues in areas with abundant water supplies.

There are challenges associated with collecting sufficient data for a full water impact assessment. Therefore organisations should prioritise their efforts to focus on the most water-intensive processes, areas and products, as well as those in areas that are considered to be at high risk of water scarcity.

3.2.5.7 Economics

One of the challenges for water management is the collection of adequately detailed data, which requires monitoring water flows. Monitoring using sub-meters requires careful design analysis to suit the local situation. Capital costs vary depending on the type of water flow meter – an overview is provided in Table 3-9.

Table 3-9: Cost of water sub-metering systems

Type of submeter	Pipe size (mm)	Cost (€)
Positive displacement	6 - 51	720 – 2,770
Turbine	3 - 203	200 – 1,440
Vortex shedding	6 - 102	340 – 1,550
Portable ultrasonic	6 - larger	920 – 4,520
Permanent ultrasonic	51 - 127	1,700 – 2,240

Notes: Assumed conversion factor of $ to € of 0.72.

Source: (US DoE, 2011)

Monitoring and sub-metering by themselves may have relatively little impact on overall water consumption; rather, it is a tool to understand and control usage. However, the investment costs required to more accurately meter water use are likely to be offset by the savings in water costs, depending on the actions taken. For example, Ford suggest that they are increasing usage of internal water metering to identify additional water saving opportunities at the department level, which has the potential to save approximately $75,000 (€55,300) on average per plant globally (Ford, 2012).

Other aspects of a water management strategy at the site level are outlined in terms of the potential cost and payback in Table 3-10.

Table 3-10: Water saving practices for industrial applications

Item	Description	Potential cost	Potential payback
Staff training	Increase staff awareness through training, workshops and seminars	Medium (a few €100s to a few €1,000s)	Medium (less than a year)
Water balance	Data collection through site-wide survey, bills and flow measurements	Medium	Short (months)
Monitoring	Flow meters	Medium	Short (months)
Leakage identification and elimination	Inspection and repair of equipment	Medium	Medium (less than a year)
Overflow identification and elimination	Using level controllers to avoid overviews and reduce risk of flooding or pollution incidents	Medium	Medium (less than a year)

Notes: Potential costs and paybacks are for guidance only. Actual costs and paybacks will vary due to project-specific details.

Source: (Zero Waste Scotland, 2012)

3.2.5.8 Driving force for implementation

There are a number of driving forces contributing to the implementation of better water management in the automotive industry. In particular:

- Increased awareness of water scarcity and the effects of climate change on water supplies within the supply chain, and directly on automotive plants;
- Corporate social responsibility (CSR);
- Legislative requirements for discharge of effluent and wastewater;
- Integration and increased customer requirement for Environmental Management Systems;
- Reduced costs.

3.2.5.9 Reference organisations

Many automotive manufacturers recognise the need to consider areas of water scarcity in their sustainability or water management plans. Examples of tools used by different manufacturers include:

- CDP Water Disclosure (Ford, 2012), (Volkswagen, 2013);
- The CEO Water Mandate (Volkswagen, 2013);
- World Business Council of Sustainable Development Global Water Tools (Ford, 2012);
- World Resources Institute Annual Renewable Water Supply per person methodology (General Motors, 2013).

3.2.5.10 Reference literature

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3.2.6 Ecosystem management reviews and strategy

SUMMARY OVERVIEW:				
There is growing awareness of the importance of ecosystem services, and the automotive sector both impacts and relies upon these services throughout the value chain. It is considered best practice to conduct an ecosystem management review so that these impacts can be clearly understood, and to work with relevant stakeholders to minimise any issues.				
Relevant lifecycle stages				
Management	Design	**Supply chain**	**Manufacturing**	End-of-life
Main environmental benefits				
Energy consumption	Resource use and waste	Water use & consumption	Emissions to air, water, soil	**Ecosystems & biodiversity**
Environmental indicators				
• Application of techniques to assess ecosystem services to the value chain (e.g. % coverage); • Coverage of relevant scope, as determined by prioritisation (e.g. % coverage).				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Implementing an advanced environmental management system;			
Related BEMPS	• Biodiversity management			

3.2.6.1 Description

An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the non-living environment interacting as a functional unit. The Millennium Ecosystem Assessment, organised by the United Nations, defined four “ecosystem service” categories as follows (Millennium Ecosystem Assessment, 2005):

(1) Provisioning services, or goods and products obtained from ecosystems, such as food, freshwater, timber;
(2) Regulating services, or benefits from the ecosystem’s natural regulating processes involving climate, disease, soil erosion, water flows, and pollination, as well as protection from natural hazards;
(3) Cultural services, or the spiritual and aesthetic enjoyment derived from nature;
(4) Supporting services, or such natural processes as nutrient cycling and primary production that maintains other services.

The automotive industry impacts on ecosystems through resource consumption, pollution, land conversion, and other activities. The most significant potential impacts from car manufacturing are indirect, occurring through the extraction of raw materials, habitat fragmentation due to road construction, local pollution from vehicle use and the potential impacts of climate change (Ford, 2012).

The automotive industry is also directly and indirectly dependent on biodiversity, intact ecosystems and their services. This is evident in the provision of certain renewable resources that are currently used in vehicle components, for example:

- Natural rubber. The cultivation of the tree is land-intensive, and usually occurs in regions of high biodiversity, in competition with the natural ecosystems (Global Nature Fund, 2013).
- Leather: has the potential to cause significant disruptive impacts on biodiversity. The manufacture of leather requires large quantities of chemicals, and waste from the production process must be dealt with in an environmentally responsible way (Global Nature Fund, 2013).

- Filling materials such as coconut fibre or visually appealing woods for fittings (Global Nature Fund, 2013). However, the relative proportion of such materials in contemporary vehicles is low.

All of these materials grow in nature, and a sound ecosystem is required to support them.

The operational guidance in this section focusses on ecosystem management – that is, it should be considered as a subset or complement to management of wider environmental issues such as emissions and effluent. However, it should be noted that the credibility of results is highly dependent on the approaches and assumptions used, which requires a good understanding of the relationship between ecosystem change, ecosystem service provision, and economic or human wellbeing indicators. This almost always requires input from scientists and technical specialists (WBCSD, 2011).

3.2.6.2 Achieved environmental benefits

The primary environmental benefit is the conservation of natural resources, and the associated ecosystem service provision. While sometimes the consequences of depletion and degradation of ecosystem services can be mitigated (for example, water treatment facilities can sometimes substitute for the role of watersheds and wetlands in water purification), in other cases it is either more costly or impossible to do so.

3.2.6.3 Environmental indicators

The development of widely accepted indicators for ecosystem services is challenging and work in this area is ongoing. Therefore the approaches detailed in this section are binary indicators that relate to the level of uptake and scope of the approaches used:

- Technique or tool in place to assess the corporate impacts on ecosystem services (Yes/No)
- Tool covers relevant scope, as determined by prioritisation (Yes/No).

3.2.6.4 Cross-media effects

There are often trade-offs between ecosystem services (e.g. relating to carbon, water, food, landscape, etc.). Some strategies can result in increasing supply, quality or quantity of ecosystem services in certain regions of the world, while decreasing it in others (WBCSD, 2011). This aspect needs very careful consideration.

Evaluating trade-offs usually requires good, credible scientific information about the relationships, linkages and predicted environmental changes between the alternative scenarios - this often necessitates specialist expertise (WBCSD, 2011). It is not recommended that corporations attempt to value ecosystems services using in-house expertise alone – external expertise will almost always be required. Potential sources of technical expertise include universities, research institutions, governments, non-governmental organisations and consultants. Using external expertise and involving stakeholders in the process will help to mitigate any controversies due to the fact that this is an evolving field.

3.2.6.5 Operational data

The interactions between human activities and ecosystems are highly complex and constantly evolving - consequently a vast range of modelling and assessment approaches have been developed to assess these linkages.

To help companies navigate this complexity the main approach presented is based on the **Corporate Ecosystem Services Review (ESR)** (WBCSD, 2012). This was selected as it is a comprehensive yet simple scheme that was designed specifically to meet the needs of businesses, and has been successfully applied in the automotive sector. It should be noted that there are a number of other existing guidance documents that can inform good and best practice in ecosystem management (see section *3.2.6.6* on *Applicability*).

The Corporate Ecosystem Services Review was developed by the World Resources Institute with support from the World Business Council for Sustainable Development and the Meridian Institute. The methodology consists of five steps, as shown in Box 3-3:

Box 3-3: Overview of the Corporate Ecosystem Services Review methodology

1. Select the scope;
2. Identify priority ecosystem services (qualitative);
3. Analyse trends in priority services;
4. Identify business risks and opportunities;
5. Develop strategies.

Source: (WBCSD, 2012).

A detailed case study implementation of each of the steps involved in the Corporate Ecosystem Services Review is presented below, based on (Nissan, 2010).

Step 1: Select the scope

The scoping stage may focus on one product or project to begin with, and subsequently be expanded to other areas. An alternative approach is to do a high-level review to help target more detailed studies (WBCSD, 2011).

Implementation at Nissan defined the scope to cover 10 areas of the value chain, including:

- **Upstream analysis**, including mineral mining, fossil fuel sourcing, biofuel sourcing, and materials sourcing of metals and chemicals;
- **Company operations**, including manufacturing (fabrication, painting, thin-coating, assembly), logistics, and Nissan's office usage;
- **Downstream**: Customer use of Nissan automobiles, road construction and maintenance, and the recycling, disposal, and exports of scrapped cars.

Step 2: Identify priority ecosystem services

This is a screening exercise to evaluate the company's dependence and impact on more than 20 ecosystem services to help identify priority services, both in terms of whether the company depends on a service or impacts on it.

- **Dependence:** If the company is dependent on a particular ecosystem service, the company could face business risks, such as higher input costs or disruption to its operations. To evaluate this aspect, Nissan assessed two key questions:
    - Does the ecosystem service serve as an input or does it enable or enhance conditions for successful company performance?
    - If yes, does this ecosystem service have cost-effective substitutes?
- **Impacts:** If a company impacts an ecosystem service—either negatively by depleting or degrading it or positively by supplying or enhancing it. Nissan assessed two key questions:
    - Does the company affect the quantity or quality of this ecosystem service in a positive or negative way?
    - Does the company's impact limit or enhance the ability of others to benefit from this ecosystem service?

Nissan managers and external experts conducted a *rapid assessment* to determine the level of dependence and impact on each ecosystem. The results of this qualitative analysis are shown in Table 3-11.

Table 3-11: Ecosystem Services Dependence and Impact Matrix

Ecosystem services		Upstream: suppliers		Manufacturing		Downstream	
		Dependence	Impact	Dependence.	Impact	Dependence	Impact
Provisioning	Food		●				
	Fibre		●				
	Biomass fuel		●			●	
	Freshwater	●	●	●	●	●	●
	Genetic resources		●				
	Biochemicals		●				
Regulating	Air quality		●		●		●
	Climate		●		●		●
	Water		●				
	Erosion		●			●	
	Water purification & waste treatment	●	●		●	●	●
	Disease		●				●
	Pest regulation		●				●
	Pollination		●				
	Natural hazards				●		●
Culture	Recreation and Ecotourism		●		●		●
	Ethical values		●		●		●
Supporting	Nutrient cycling		●				
	Primary production						
	Water cycling						

Source: (Nissan, 2010).

It is likely that these findings can be used to inform a starting point for evaluations conducted by other automotive companies, although it is emphasised that this exercise was carried out as a rapid screening exercise and not a comprehensive review. The analysis was conducted in collaboration with Nissan managers and various external experts, including consultants from the United Nations Institute of Advanced Studies, to provide perspectives and lead the ESR-related analysis.

Step 3: Analyse priority services

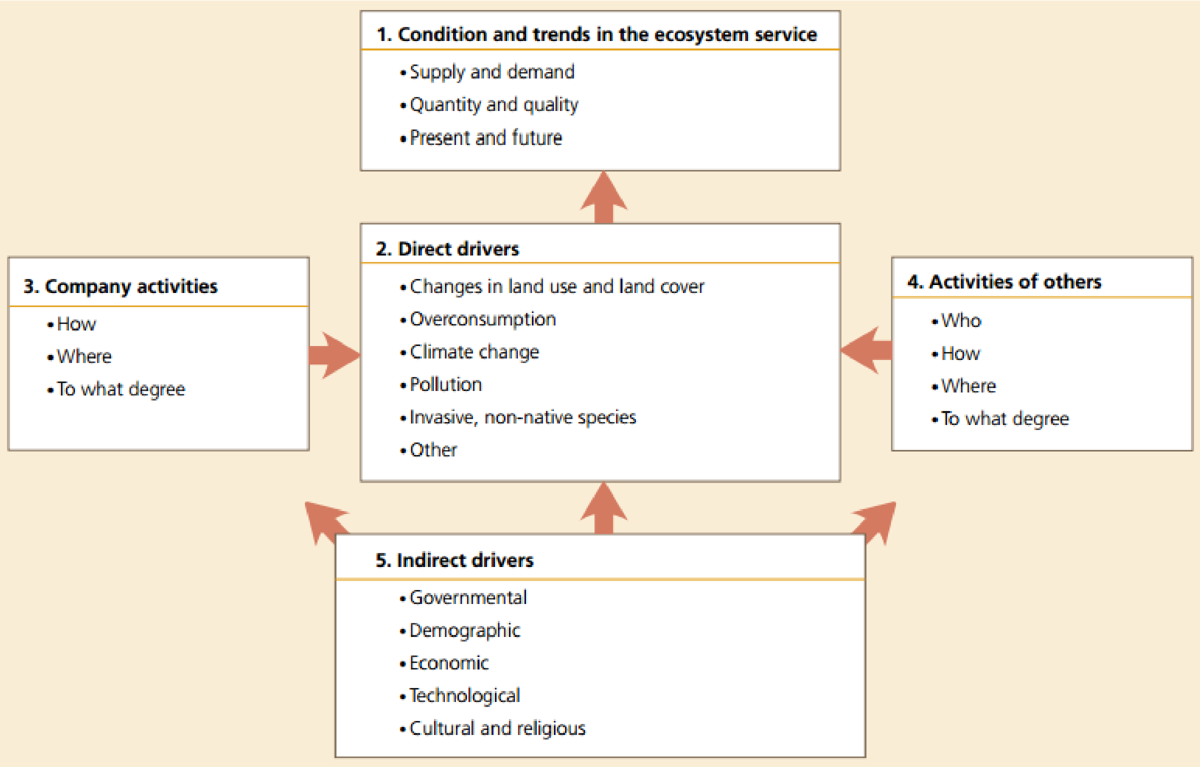
After completing the simple dependence and impact assessment table, the priority ecosystem services can be selected — those judged most likely to be sources of business risk and opportunity. Experts in the area of ecosystem services, including high profile university professors and NGOs offered detailed information on the conditions and trends of ecosystem services. Though not explicitly mentioned in these seven ecosystem services, changes in ecosystems have an impact on the biodiversity inherent in these ecosystems (Nissan, 2010).

For the trends analysis, research should be conducted to answer the following five questions:

1. What are the conditions and trends in the supply and demand of the ecosystem service?
2. What direct drivers underlie these trends?
3. What is the company's contribution to these drivers?
4. What is the contribution of others to these drivers?
5. What indirect drivers underlie these trends?

These five questions can provide a comprehensive understanding of the important trends for priority ecosystem services. A framework for the analysis is shown in Figure 3-5.

Figure 3-5: Ecosystem service trends and drivers framework



Source: (WBCSD, 2011)

Based on this assessment, key areas selected as priorities for Nissan and the broader automotive sector were (Nissan, 2010):

1. **Freshwater**: From "well to wheel," the automotive sector significantly depends upon access to water. This can deplete the quantity of freshwater available;
2. **Air quality regulation**: The automotive sector strongly impacts ecosystem air quality regulation services along the entire value chain, from fossil fuel sourcing to manufacturing, logistics, and finally customer automobile use;
3. **Climate regulation**: Greenhouse gases and aerosols emitted into the atmosphere largely through fossil fuels, biofuels, and material sourcing, as well as through company operations and customer automobile use;
4. **Water regulation**: Mineral mining and fossil fuel sourcing impact the water storage potential in an ecosystem or landscape;
5. **Erosion regulation**: Fossil fuel, biofuel, and material sourcing and mineral mining all significantly negatively impact vegetation and soil retention. Customer automobile use and road construction indirectly impact erosion regulation through infrastructure development;
6. **Water purification and treatment:** The automotive sector is highly dependent on freshwater and thus naturally dependent on the ability of ecosystems to filter and decompose organic wastes and pollutants in water;
7. **Natural hazard regulation**: The ability to regulate natural hazards can be highly impacted by society's infrastructure development choices. For example, filling in coastal wetlands to develop scenic ocean-view roads may make the area and those depending on this infrastructure vulnerable to coastal hazards.

Step 4: Identify business risks and opportunities

There are five main categories of business risks and opportunities associated with the degradation and enhancement of ecosystem services:

1. **Operational risks** relate to a company's day-to-day activities, expenditures and processes;
2. **Regulatory and legal risks** include government policies, laws, and court actions;

3. **Reputational risks** affect a company's brand, image, "goodwill" and relationships with their customers and other stakeholders;
4. **Market and product risks** relate to product and service offerings, consumer preferences, and other market factors that affect corporate performance;
5. **Financing risks** affect the cost and availability of capital to companies. CEV can be used to identify cost-effective "no net loss" scenarios for major developments.

There are many ways to identify possible business risks and opportunities. One method that proved useful in case study examples was to begin by holding a structured brainstorming session (WBCSD, 2011). Desk-based research can also supplement the results. Expert consultation or further research may also be needed, as well as commissioning original analysis.

As a starting point, the case study implementation example, Nissan focussed specifically on assessing the main business areas affected by them, namely (Nissan, 2010):

1. Energy sourcing;
2. Mineral and material sourcing;
3. Water usage.

Step 5: Develop strategies

The fifth step is to develop and prioritise strategies for minimising the risks and maximising the opportunities identified during step 4. Similar techniques to those described in the previous step are also useful here (i.e. brainstorming, research and stakeholder collaboration).

In addition, reviewing actions taken by other companies facing similar issues can help to trigger additional ideas – see for example, Table 3-12. Further guidance on strategies to mitigate specific impacts is also referenced where provided elsewhere in this document.

Table 3-12: Nissan case study: Impacts and strategies for the automotive sector

Impacts	Strategies	Further guidance in this document
Energy sourcing		
Many of the major impacts are during the use phase of the vehicle	Production of more fuel-efficient vehicles was highlighted as a priority	This aspect is covered under other policies, such as the car CO_2 Regulations
Impact on global warming from fossil-fuel based electricity generation	The use of fossil fuels in electricity generation can be significantly reduced, such as by expanding solar and wind power generation	See *Section 3.4.4 on Alternative energy sources*
Mineral and material sourcing		
The development of mineral resources may involve stripping away the topsoil or cutting down forests on a large scale.	Metals account for approximately 80% by weight of the materials used to build a vehicle, making automobiles highly dependent on mineral resources. Strategies should aim to conserve resources and to promote recycling in order to reduce the quantities of virgin mineral resources needed. The ultimate goal of resource recycling is 100% recovery of ELVs	See *Section 3.5* on key manufacturing processes

Impacts	Strategies	Further guidance in this document
The impact of the extraction of mineral resources on various ecosystems is one risk factor for the automotive sector in the procurement of necessary resources	Efforts, at the time of procurement, to select resources having minimal impact on ecosystem. It is important for the automotive sector to promote materials stewardship and to give precedence to the procurement of resources that take into account the minimisation of the impact on ecosystems	See *Section 3.3.3 on Integrating environmental requirements into supply chain management*
Water usage		
Water stress is defined as a ratio (critical ratio) of the volume of water withdrawn annually to that which is potentially available or renewable. Due to the rise in water consumption, some two-thirds of the world's population are expected to live in regions with water stress by 2025.	It is important for the automotive sector to promote materials stewardship together with the mining sector and to give precedence to the procurement of resources that take into account the minimisation of the impact on ecosystems. Water-use assessments were carried out at all plants. The highest-risk plants were given water reduction targets	See *Section 3.2.5 on Water use strategy and management*

Source: Adapted from (Nissan, 2010).

3.2.6.6 Applicability

The approaches outlined can readily link with many other existing company processes and analytical techniques, such as life cycle assessments, land management plans, economic impact assessments, company reporting, and sustainability appraisals (WBCSD, 2012).

A growing number of other tools and approaches are available, which can make it challenging to select the most appropriate for each organisation. A decision tree to help organisations choose what scale of assessment and what tools would best support decision-making has been developed by the WBSCD – available at: http://www.wbcsd.org/eco4biz2013.aspx

The Corporate Ecosystem Services Review (ESR) was chosen as best practice because it represents a credible and proven low-cost tool to help companies when they first start to assess their interactions with ecosystem services. The ESR can serve as a management-level guide to help identify, prioritise and respond to the risks and opportunities of ecosystem services. It is one of the few tools that are suitable for immediate and widespread use in a corporate setting (Bagstad et al, 2013). For many activities in the automotive sector, simple screening and assessment tools are likely to offer the best trade-off between cost-effectiveness and added value. Other tools may become appropriate as companies develop and refine their strategies, although the complexity and cost of these tools also increases.

3.2.6.7 Economics

In most cases, ecosystem service valuation does not need to be lengthy or expensive (WBCSD, 2011), although the cost and effort involved scales with the complexity of the tools used. Some illustrative figures suggest that:

- At least ten hours is needed to conduct an initial qualitative review of ecosystem services (such as the suggested Corporate Ecosystem Review methodology) or to use simple spreadsheet models (Bagstad et al, 2013). However, the time taken depends significantly on the scope and level of detail, and involvement of stakeholders and conducting workshops will add to this time requirement;
- Application of spatially explicit modelling tools requires hundreds of hours of work by an experienced analysis (Bagstad et al, 2013). Therefore such assessments should only be conducted where there is a strong need for insights and where the added value is clear. In practice, there are unlikely to be many applications in the automotive industry for which this level of analysis is required.

Direct cost and benefit information is difficult to present, as it is highly dependent on specific business operations and approaches. Broadly, better management of ecosystems is expected to lead to better risk management, thereby increasing revenue, saving costs, boosting asset values and potentially share prices (WBCSD, 2011).

3.2.6.8 Driving force for implementation

There is increasing evidence that ecosystem degradation has a material impact on companies through undermining performance, profits, their license to operate and access to new markets (WBCSD, 2011).

Mainstreaming ecosystem considerations into business is becoming increasingly important in order to deal with the challenges of a resource-constrained world (WBCSD, 2011).

In addition to materials, vehicle manufacturing is often reliant on biodiversity and intact ecosystems to supply a local water supply (of sufficient quality and quantity) for production processes (Global Nature Fund, 2013). Finally, ecosystems serve as a sink for emissions from production processes. Companies must also anticipate that ecosystem valuation will be more consistently incorporated into public policies, regulations, and political decisions. For example, in 2011 the European Union adopted the Biodiversity Strategy to 2020. The strategy aims to halt biodiversity loss in the EU, restore ecosystems where possible, and step up efforts to avert global biodiversity loss.

3.2.6.9 Reference organisations

An analysis of the sustainability reporting of some major automobile manufacturers (BMW, Daimler, Fiat, Ford, GM, Honda, Mitsubishi Motors, Nissan, Toyota, Volkswagen) shows that the issue of biodiversity has been established in company targets, albeit to varying degrees of importance (Global Nature Fund, 2013). However, approaches to ecosystem services and management are heterogeneous, and mainly focus on the established topics of climate change, resource scarcity and water (Global Nature Fund, 2013). These aspects play an important role in reducing the progressive loss of biodiversity.

The main guidance described is based on the Corporate Ecosystem Services Review (WBCSD, 2012), with a case study implementation adapted from (Nissan, 2010).

3.2.6.10 Reference literature

Bagstad et al (2013) A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Available at: http://www.sciencedirect.com/science/article/pii/S221204161300051X (accessed 06/05/2014)

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3.3 Vehicle design and supply chain management

3.3.1 Section overview and technique portfolio

Vehicle design and production involves the use of advanced materials, complex designs with implications for in-use emissions and extensive supply chains. Therefore, understanding and managing environmental impacts throughout the entire vehicle lifecycle is crucial to reduce total impacts. Without integrated approaches, burden-shifting could easily occur.

To this end, most major car manufacturers have developed their own design methodologies and supplier sustainability standards, which typically include aspects of environmental protection. However, the stringency and extent of these environmental requirements varies widely between organisations.

The best practices described in this section outline integrated methods to manage trade-offs between different lifecycle stages, different environmental impact categories and different world regions:

- **Design for sustainability using Life Cycle Assessment (LCA):** Environmental aspects should be considered from the earliest stages of design. Typically the major environmental impacts occur during the use phase of the vehicle; however with the increasing introduction of advanced low carbon technologies, the manufacturing stages are becoming more important. Nevertheless, the use phase is likely to continue to dominate in the near term - the key aim of integrating LCA into vehicle design is to optimise environmental impacts over the lifecycle, paying attention to trade-offs between different lifecycle stages;
- **Integrating environmental requirements into supply chain management:** The majority of environmental impacts from the production stage of a vehicle are found in the supply chain; hence considering the environmental impacts is extremely important. Supply chain management activities have been found to improve the environmental, economic and operational performance of firms through selection of suppliers, transfer of technology, greater efficiency and innovation. Collaboration, training and development with suppliers is of particular importance for the automotive industry, where the products demanded are highly sophisticated, relationships are long-standing and standardised eco-labels may not exist.

These BEMPs are considered to be crucial to the overall sustainability of the sector, and have the potential to identify and unlock significant environmental improvements throughout the vehicle lifecycle. The guidance has been extensively tailored to the specific situation of the automotive industry.

3.3.2 Design for sustainability using Life Cycle Analysis (LCA)

SUMMARY OVERVIEW:				
Conducting life cycle assessment (LCA) helps to identify potential improvements and trade-offs between different environmental impacts, as well as helping to avoid shifting environmental burdens from one part of the product lifecycle to another. Best practice LCAs in the automotive sector will be carried out extensively during the design phase, set specific goals for improvement in different environmental impacts and ensure that these targets are met.				
Relevant lifecycle stages				
Management	**Design**	**Supply chain**	**Manufacturing**	**End-of-life**
Main environmental benefits				
Energy consumption	**Resource use and waste**	**Water use & consumption**	**Emissions to air, water, soil**	Ecosystems & biodiversity
Environmental indicators				
• Conducting LCA to inform design decisions (% designs) • Improvements in environmental indicators (CO_2, energy consumption, pollution etc) for new model designs compared to previous model designs (% improvement) •				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	**N/A**			
Related BEMPS				

3.3.2.1 Description

Lifecycle design is a framework for integrating environmental considerations into product development. While the majority of automotive manufacturers already use life cycle assessment (LCA) as a management tool, in practice the approach to using LCA data varies widely. In addition, the LCA data itself varies widely in terms of their quality, reliability, replicability and therefore also in terms of their environmental improvement potential (Chanaron, 2007).

The main principles of best practice are listed below (Telenko, 2008):

A. **Ensure sustainability of resources**: aims to address resource depletion by encouraging reuse of resources such as materials and components, and renewability of consumed resources such as energy. Of particular relevance to the automotive industry is the concept of reusing common parts and remanufactured components and a growing interest in using renewable resources to manufacture plastics (see separate guidance in *Section 3.5: Key Manufacturing processes*

B. **Ensure healthy inputs and outputs:** this principle requires elimination of hazardous substances as well as the conversion of waste to useful materials (see separate guidance in *Section 3.5: Key Manufacturing processes*

C. **Ensure minimal use of resources in production and transportation:** this encourages designers to consider how to reduce material waste in production and packaging. A particularly important aspect is the management of the supply chain (see separate guidance in *Section 3.3.3: Integrating environmental requirements into supply chain management)* as well as design for optimally lightweight structures (see below);

D. **Ensure minimal use of resources during use phase:** this motivates the product design to be efficient in energy consumption and to incorporate functions that guide the user to reduce environmental impacts. While the use phase of vehicles is covered extensively under other legislation, it is nonetheless extremely important from a lifecycle perspective;

E. **Ensure appropriate durability of the product and components**: appropriate durability of a product can avoid additional processing and transportation steps, as well as postponing waste, recycling and remanufacturing steps. This encompasses two main aspects – durability for long life, coupled with the ability to repair or upgrade the product to current best practices. In the automotive industry, excessively long-lived products may exclude cars from technological improvements in terms of performance, safety, emissions etc., as well as potentially having an excessive price – therefore this aspect needs to be balanced against other environmental and consumer needs (Ernst, 2013);
F. **Enable disassembly, separation and purification**: includes steps to facilitate remanufacturing, reuse, repair and upgrading by incorporating these features at the design phase (see separate guidance in *Section 3.5: Key Manufacturing processes)*.

Some manufacturers have also introduced concepts for evaluating the product's sustainability which go beyond LCA to incorporate social and economic factors – see *3.3.2.10* on *Emerging techniques* for more information on this aspect.

Material choice is one of the key elements in vehicle design in order to ensure that the environmental impacts at the end-of-life stage are minimised. However, this is a challenging task due to the complexity of the vehicle components, as well as the need to balance many factors such as performance, safety and recyclability. For example, the increasing fraction of plastics and aluminium in modern vehicles, as well as the introduction of carbon fibre, are likely to make recycling more challenging. Yet the use of lightweight materials such as these will improve the fuel efficiency of vehicles during the use stage. These trade-offs are best managed using a life cycle approach

"Design for dismantling" principles aim to optimise the separation of components and materials at the end of a product's life. Complex dismantling procedures require greater time and effort, and therefore the economic viability of these operations is reduced (Chiodo, 2005). Thus, increasing the efficiency of the dismantling process is likely to facilitate higher rates of material and component recovery, as well as increasing the value of the recycled material (Nemry, et al., 2008).

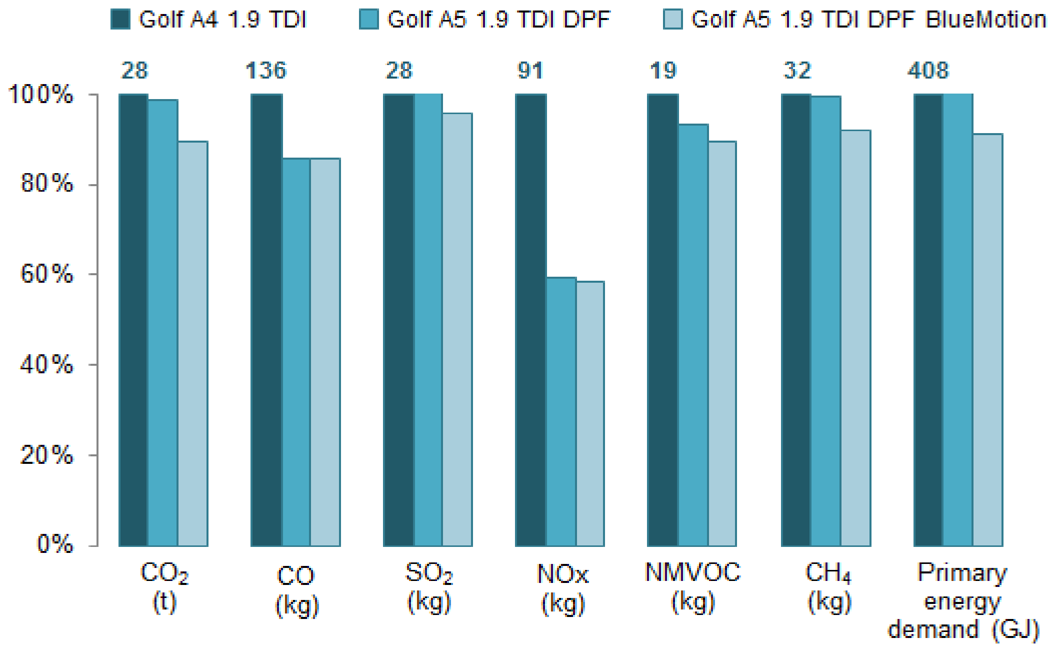
Some manufacturers have focussed on post-shredder technologies to achieve targets set in the ELV Directive, while others have chosen to prioritise higher levels of dismantling (de Medina et al, 2007). For the purposes of compliance with the ELV Directive, either technique is suitable. It appears that many European manufacturers prefer the post-shredder recycling option. Nevertheless, there are examples of positive results achieved through higher dismantling, particularly from Japanese manufacturers. For certain components, dismantling may be preferable to post-shredder treatment, particularly where manufacturers are able to reclaim the materials and incorporate them into new parts, thus establishing closed-loop recycling processes and enhancing security of supply.

3.3.2.2 Achieved environmental benefits

A major goal is to avoid shifting environmental burdens from one part of the product lifecycle to another. The analysis will typically involve setting specific goals for the levels of different environmental impacts and ensure that company targets on the environmental impacts of new models are met.

As an example, Figure 3-6 shows environmental improvements for new Volkswagen Golf models compared to their predecessors (VW, 2008). Environmental improvements across a range of categories were achieved, mainly due to increased fuel efficiency of the models.

Figure 3-6: Environmental improvements achieved for successive Golf models



Notes: Assumed lifetime mileage of 150,000 kilometres. The 77 kW 1.9-litre TDI with diesel particulate filter (the best-selling Golf by far) is compared with its almost equally powerful predecessor and with the Golf Bluemotion.

Source: (VW, 2008)

The key aim is to optimise environmental impact over the lifecycle, paying attention to trade-offs between different lifecycle stages. For example, reducing vehicle weight through the use of materials such as aluminium and carbon fibre will reduce energy consumption and carbon emissions during the use phase of the vehicle. However, these materials tend to increase energy consumption in the production phase. The use of LCA can help identify these trade-offs so that options with the lowest environmental impacts over the lifecycle can be selected and the environmental credentials can be demonstrated to internal and external stakeholders.

Life cycle assessments can vary considerably between studies due to differences in vehicle composition and processes, and also due to variations in the types of energy used by the plant (including the local electricity generation mix). Emission levels of sulphur dioxide and particles depend on the composition of fuels used in hot water boilers and burners, while emissions of NOx, carbon monoxide and hydrocarbons depend on the technical aspects of the combustion process (Volvo, 2013).

When looking at *single* environmental categories, it is relatively easy to identify the best option by minimising the impact across the whole life cycle. However, when considering impacts across *several* environmental categories, it is more challenging to compare decisions, especially where improvements in one category lead to trade-offs in another – see *3.3.2.4* on *Cross-media effects* for more details on this issue.

3.3.2.3 Environmental indicators

At the implementation level, it is best practice to integrate LCA into all new design decisions. For example, Daimler indicates that the environmental aspects of design are considered long before the first prototype is developed in CAD software (Chanaron, 2007). General indicators for this BEMP include:

- Conducting LCA to inform design decisions (% designs)
- Improvements in environmental indicators (CO2, energy consumption, pollution etc) for new model designs compared to previous model designs (% improvement)

Typically, the environmental impact categories considered in an LCA include energy and raw material consumption; emissions to air, water and soil; and solid wastes (Chanaron, 2007). Common indicators include:

- Global warming potential (tCO_2-eq);
- Acidification potential (kg SO_2-eq);
- Eutrophication potential (kg PO_4-eq);
- Photochemical pollution (kg C_2H_4);
- Water consumption/use (m^3);
- Primary energy demand (GJ);
- Material use rate (kg);
- Restricted material usage (kg);
- Ecotoxicity (kg toxic substance released, expressed as 1,4-dichlorobenzene (DCB) equivalent).

These are measured for the chosen functional unit, such as a vehicle or component over its lifetime.

3.3.2.4 Cross-media effects

Trade-offs between different *lifecycle stages* and *environmental impact categories* are often apparent when using LCA. For example, the LCA of the 2009 Mercedes S 400 Hybrid compared to the S 350 shows that the Hybrid variant consumes 45% more copper ore and 55% more rare earth materials, both connected to the manufacture of the hybrid components which in turn save fuel and reduce CO_2 emissions over the use phase of the vehicle (Daimler 2009).

Ideally, improvements in all areas can be achieved but in practice this is not always possible. Quantitative approaches attempt to rate different impact categories against each other, for example using a single overall metric of environmental impact. However, this approach is not advised in ISO 14044:2006 as it may compromise the objectivity of the assessment.

In LCA guiding principles it is often recommended to increase the life of the product, and in many cases this is indeed a good strategy. However, for the automotive industry in particular, life extension may sometimes increase environmental impacts - different products require different approaches. For instance, engines have continued to improve as emissions standards become more stringent. On the other hand, durable car bodies may provide a stable platform for a longer time, reducing the impacts associated with investments in tooling, pressing, etc. (Warren & Rhodes, 2006).

The selection of materials has an impact at every stage of the life cycle of a vehicle and cannot be considered only in terms of the end-of-life of a vehicle. For example, the recycled foam used by Ford in seat padding, is heavier than that of virgin material, and therefore will have an impact throughout the in-use phase of the vehicle (Ford - personal comm., 2014). Focussing only on "Design for Recycling" would disregard other important factors, such as energy-efficiency considerations. Therefore, material selection factors should be considered as a subset of overall sustainable design.

Recycled material quality is highly influenced by the contamination rate. If materials that are not thermodynamically compatible cannot be separated through dismantling or in the shredder, they will be lost into one of the recyclate streams.

In all cases, the environmental benefits of dismantling should be compared to alternative end-of-life options such as post-shredder recovery.

3.3.2.5 Operational data

Examples of firms using best practice methods for conducting LCAs are outlined in Table 3-13.

Table 3-13: Examples of best practice implementation for each step

Step	Example
Use of internationally accepted standards	International standards for conducting LCA have been defined in ISO 14040 and 14044, which are widely accepted and generally applicable (Chanaron, 2007). BMW use the lifecycle engineering approaches in accordance with ISO 14062 (BMW, 2013)
Integrating LCA into decisions at the earliest stages of design	Daimler indicates that the environmental aspects of design are considered long before the first prototype is developed in CAD software (Chanaron, 2007) BMW take into account the environmental effects throughout the vehicle lifecycle, from the selection of materials, product, use and recycling. The sustainability targets have the same significance as other criteria in the development of the vehicle, such as weight and cost (BMW, 2013) Toyota's Eco-vehicle assessment system is used to conduct LCA in the design stage. The software is linked to a database that holds information regarding all of Toyota's parts/materials. This allows the LCA impacts to be calculated automatically, when virtually adjusting the design (Toyota - personal comm., 2014).
Establishing cross-discipline teams	At Daimler, cross-discipline teams include experts in life cycle assessment, disassembly and recycling planning, materials and process engineering, design and production (Chanaron, 2007).
Establishing environmental improvement targets	At Volkswagen, each new model is required to consume less fuel and generate lower emissions than the current model. Its production must consume fewer raw materials and its components must be at least 95 percent recoverable (VW, 2010).
Data for the complete value chain, including suppliers	To gather data for the value chain, suppliers can be required to fill out a standardised template on materials, energy, emissions and transport distances. The supplier data collection approach for the association of German OEMs (VDA) aims for a minimum of 80% data completeness in 80% of the time provided within days or weeks (rather than months) (VDA, 2003). LCA models can also be drawn up on the basis of parts lists or material data sheets.
Clear and transparent communication to the public, including underlying data and assumptions	While some manufacturers feel that LCA data is commercially sensitive and are reluctant to publish their results, others make whole vehicle LCA reports publically accessible. For example, Volkswagen publishes its LCA reports dealing with all stages of the life cycle, including assessing the environmental impacts in the supply chain (Chanaron, 2007).

One of the key challenges is gathering adequate data. Particular difficulties include:

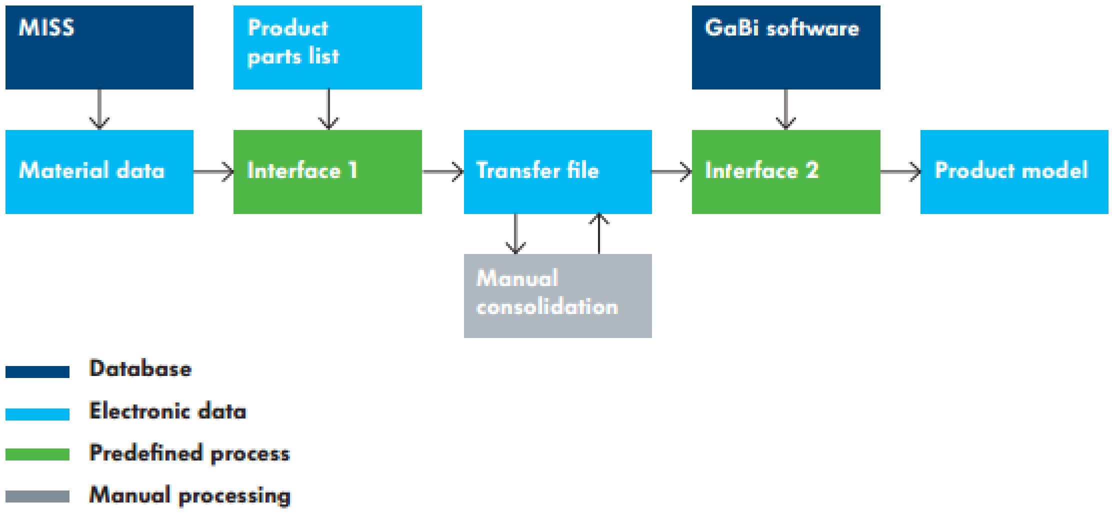
- Location-specific data should be used where possible to ensure the data are representative, although it is not always available. In these cases, national data could be substituted. For example, Volkswagen uses data for Europe where possible as this is considered the appropriate geographical area, rather than German data. Assumptions on upstream supply chains for energy sources and materials are kept constant so that differences between models can be attributed more clearly to design/production decisions rather than fluctuations in raw material and energy supply chains (VW, 2008);
- Data on environmental impacts tend to be limited in the case of new supplier parts where the production process are unfamiliar, or when assessing technologies which are still in the early stages of development (VW, 2008). In such cases, a simplified modelling approach may be used to gain a high level insight into likely impacts until better data become available. In addition, working with experts can also help to fill data gaps;

- Calculations can be very time and resource-intensive. Where resources are constrained, greater effort should be directed towards the aspects that dominate the overall environmental impacts ("hot spots");
- Many materials used in the automotive industry are highly innovative and full data may not be available. The use of data on close substitutes is an important interim strategy to gain initial results. Further analysis may only be required if the data gap may have a significant impact on the overall analysis – in such cases, provision of peer-reviewed data on new materials can be sought out.

Due to the above-mentioned issues, the data burdens for a full LCA are potentially massive. Furthermore, each vehicle model can have hundreds of variants.

To simplify the approach while still gaining similar insights, modelling processes can be used to fill data gaps. For example at VW a simplified interface is used to model the energy-consuming processes and materials based on using LCA software (GaBi) – see Figure 3-7. The first interface assigns information from parts lists to relevant component information (part designations and quantities) to the relevant component information (materials and weights) from the Material Information System (MISS) and converts it into a transfer file that is then manually checked for quality. The second interface links to related data sets in the GaBi LCA software. This greatly reduces the time required to generate LCAs.

Figure 3-7: Simplified LCA modelling process used at VW



Source: (VW, 2009)

Material inputs, processing procedures and selection of data in GaBi are standardised as far as possible. **"Product data"** describes the product itself, including (VW, 2009):

- Information on parts, quantities, weights and materials;
- Information on fuel consumption and emissions during utilisation;
- Information on recycling volumes and processes.

"Process data" includes information on manufacturing and processing steps such as electricity provision, the production of materials and semi-finished goods, fabrication and the production of fuel and consumables. This information is either obtained from commercial databases or compiled by Volkswagen as required.

With respect to materials, using materials that are more recyclable does not automatically mean that they are more environmentally benign, or have better life cycle performance. Nevertheless, there is still a role for overarching principles focussing on material selection for several reasons:

- To ensure that options for recycling are not fundamentally restricted by the choice of materials. Ultimately, the overall recyclability of any product will also be determined by the methods of assembly/disassembly and market conditions such as the price for recycled materials (which are subject to variations);

- To reduce the burden on manufacturers when trying to optimise environmental performance. The potential choice of materials and combinations thereof are so numerous that conducting a life cycle assessment on all of these would be extremely time-consuming and expensive.

The key factors that affect dismantling are summarised in Table 5-4, along with the potential opportunities for improvement discussed above.

Table 3-14: Summary of factors affecting the feasibility and ease of dismantling

Factors	Improvement opportunities
Type and number of fasteners	• Select fasteners that are easy to disassemble • Reduce the number and type of fasteners • Avoid use of adhesives where possible
Visibility and access	• Use CAD-aided design to improve access, layout and ease of removal from the vehicle • Facilitate access to fasteners (e.g. through holes) and avoid using hidden links where possible • Use markings to guide dismantlers
Tools or procedures required	• Make use of improved and standardised tools • Make use of Active Disassembly using Smart Materials (ADSM)

Source: Adapted from (ECO 3E, 2014), (Chiodo, 2005) and (Nemry, et al., 2008).

3.3.2.6 Applicability

In principle, there are no limits to the applicability of LCA to inform design decisions at the level of the vehicle, as well as individual parts and materials. However, most SMEs lack the expertise and resources to address the requests for life cycle environmental performance information, and additional support may be needed (European Commission, 2013).

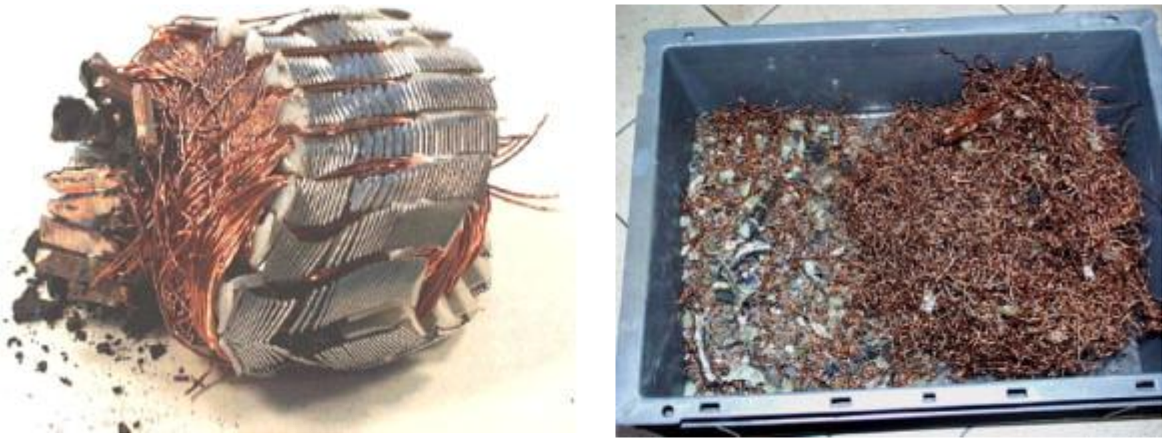
There are also limits to current LCA methodologies, as some impact categories are not well accounted for in LCA methodologies – for example, biodiversity loss and indirect effects due to displacement of agricultural production. Additional approaches may therefore be useful to supplement LCA methodologies.

LCA is also an ineffective tool for comparison of vehicles inter-OEM, as the boundaries, parameters and data sets used can differ considerably, even when following ISO standard guidelines (Toyota - personal comm., 2014)

Design is vital for ensuring materials can be separated and recovered, and this in turn makes recycling operations more viable. The main application is likely to be to the non-metallic fractions, which are typically more challenging to recycle. However, this best practice can also improve material selection for metallic components. As an example, an electric motor was redesigned according to the principles outlined above. The materials were mainly of steel and copper, which normally do not present any problems for recycling. However, in this case the high ductility of the copper, as well as the connection between the copper coil and the foliated steel rotor meant that the materials could not be recovered in the shredding process (see Figure 5-3). Since copper is an important contaminant of recycled steel, the subsequent quality of material was reduced. During redesign, the armature material was changed to low ductility steel alloys. This allowed the complete separation and recovery of the copper.

Figure 3-8: Improvements in electric motor shredding operations due to material selection

Shredder problems before component redesign ***Separation after material changes***



Source: (Froelich et al, 2007)

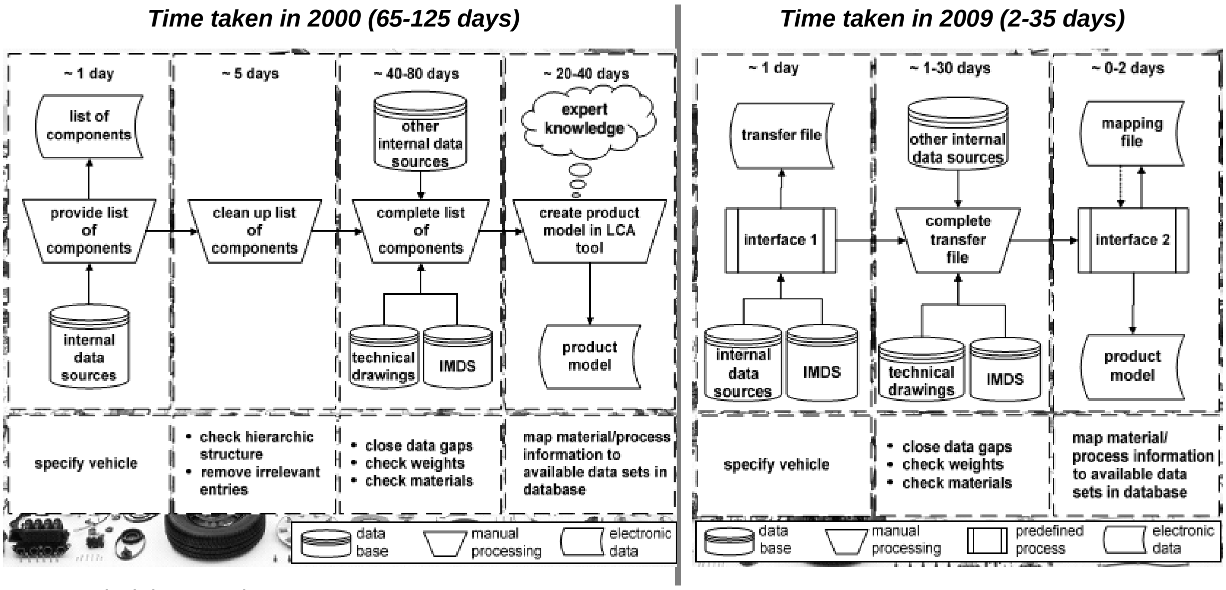
3.3.2.7 Economics

A detailed life cycle inventory analysis is a complex and data-intensive process due to the large number of parts and complex supply chains – a typical inventory includes more than 40,000 unit processes and more than 2,000 inputs and outputs (Finkbeiner, 2013). Thus, conducting LCAs to a high standard requires significant investment in the form of hiring and training staff, obtaining specialist software, working with suppliers, building a database, etc. For example, Fiat estimated that a full LCA on a vehicle can take between four and six months to complete (Fiat - personal comm., 2014); however, the time taken can be significantly reduced by using streamlined approaches in order to enable resources to be concentrated on the most important impacts – for instance, VW has reportedly reduced the time taken to less than a month (VW, 2008).

Procedures for a critical review of comparative LCAs are laid down in the ISO 14040 standard. This involves commissioning external experts for verification.

Initially, conducting a full LCA can be very time consuming, but significant improvements can be expected as manufacturers fill their databases and familiarise themselves with the procedures required. As shown by Figure 3-9, experience and software improvements have permitted Volkswagen to reduce the time for an LCA from around 65-125 days in the year 2000 to around 2-35 days in 2009. This was achieved by focussing on increasing automation of the manual processing steps through developing internal transfer files that contained pre-populated basic data on components. This also improved the consistency of LCA processes carried out within the company.

Figure 3-9: Procedure and time for conducting an LCA at Volkswagen in 2000 versus 2009



Source: (Krinke, 2009)

The automotive industry is currently dependent on raw materials (including certain precious metals) for manufacturing, and this represents a major challenge to supply management. Selection of materials to enable better recycling is potentially very beneficial where the manufacturer can retrieve the materials for recycling at a high purity level, at the end of the vehicles life – in such cases there may be more of an economic incentive to select certain materials

3.3.2.8 Driving force for implementation

At least initially, one of the main drivers for engaging in LCA was linked to political pressures from European institutions and environmental organisations (Chanaron, 2007).

Since LCA is used by manufacturers both at the vehicle design stage to set targets for environmental impacts and to identify ways of reducing the vehicle's environmental burden as well as for communicating a vehicle's environmental credentials it is likely that efforts to maintain a positive brand image and advertise new vehicle models are further driving forces for using LCA.

A key driver in Europe is the End-of-Life Vehicle Directive (2000/53/EC), which requires the automobile industry to take responsibility for the proper disposal and recycling of end-of-life vehicles. The subsequent Certification ("RRR") Directive (2005/64/EC on reusability, recyclability and recoverability) further encourages the recycling and recovery of component parts of end-of-life vehicles by obliging manufacturers to incorporate recycling from the vehicle design stage onwards.

Increasing concern over the scarcity of raw materials is another incentive to focus on material selection within vehicles, in order to ensure they can be more effectively recovered at the end-of-life stage. Closing-the-loop, on material recovery, has been an important incentive for Toyota's development of TSOP (Toyota - personal comm., 2014).

3.3.2.9 Reference organisations

Organisations that provide a large amount of LCA information for their vehicle models include:

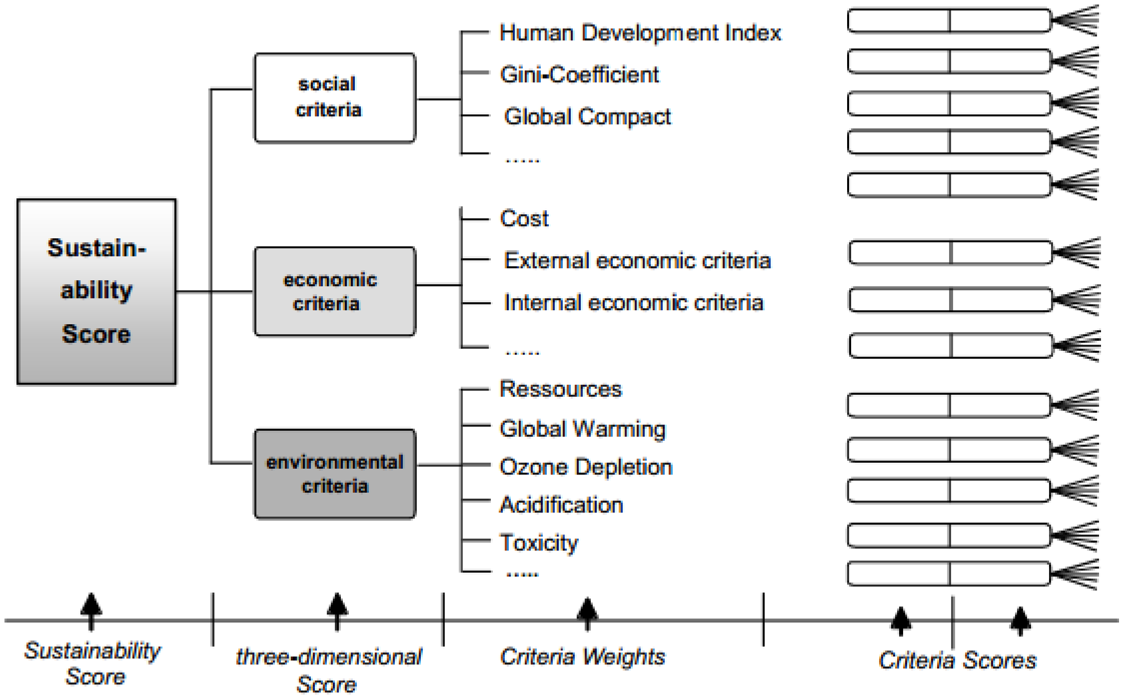
- Volkswagen – see for example (VW, 2008);
- Daimler – see for example (Daimler, 2009).

3.3.2.10 Emerging techniques

Recent developments in the field have shifted from a focus on pure LCA, which represents the state-of-the-art with respect to environmental impacts, towards including economic and societal aspects. The economic dimension includes calculations of cost and performance, while the societal aspects are mainly qualitative indicators that are in their infancy and hence selection of appropriate indicators is a

challenge (Finkbeiner, 2010). While these newer methods may become interesting in the longer term it is not clear that they provide a coherent or practical approach for the automotive industry.

Figure 3-10: Lifecycle Sustainability Assessment framework, addressing social, economic and environmental aspects



Source: (Finkbeiner, 2010)

3.3.2.11 Reference literature

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3.3.3 Integrating environmental requirements into supply chain management

SUMMARY OVERVIEW:				
The concept of integrating environmental requirements into the supply chain involves building environmental criteria into the vendor assessment process. Frontrunner organisations require all of their major suppliers to have certified environmental management systems, set targets for environmental criteria and conduct audits of high risk suppliers to ensure compliance. This is supported by training and collaboration with suppliers to ensure that their environmental performance improves.				
Relevant lifecycle stages				
Management	Design	**Supply chain**	Manufacturing	End-of-life
Main environmental benefits				
Energy consumption	**Resource use and waste**	**Water use & consumption**	**Emissions to air, water, soil**	**Ecosystems & biodiversity**
Environmental indicators				
• Percentage of suppliers (by number or by purchasing budget/value) that comply with required standards according to internal or external audits; • Percentage of suppliers that flow down requirements to their own suppliers.				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	**N/A**			
Related BEMPS	• Implementing an advanced environmental management system; • Design for sustainability using Life Cycle Assessment			

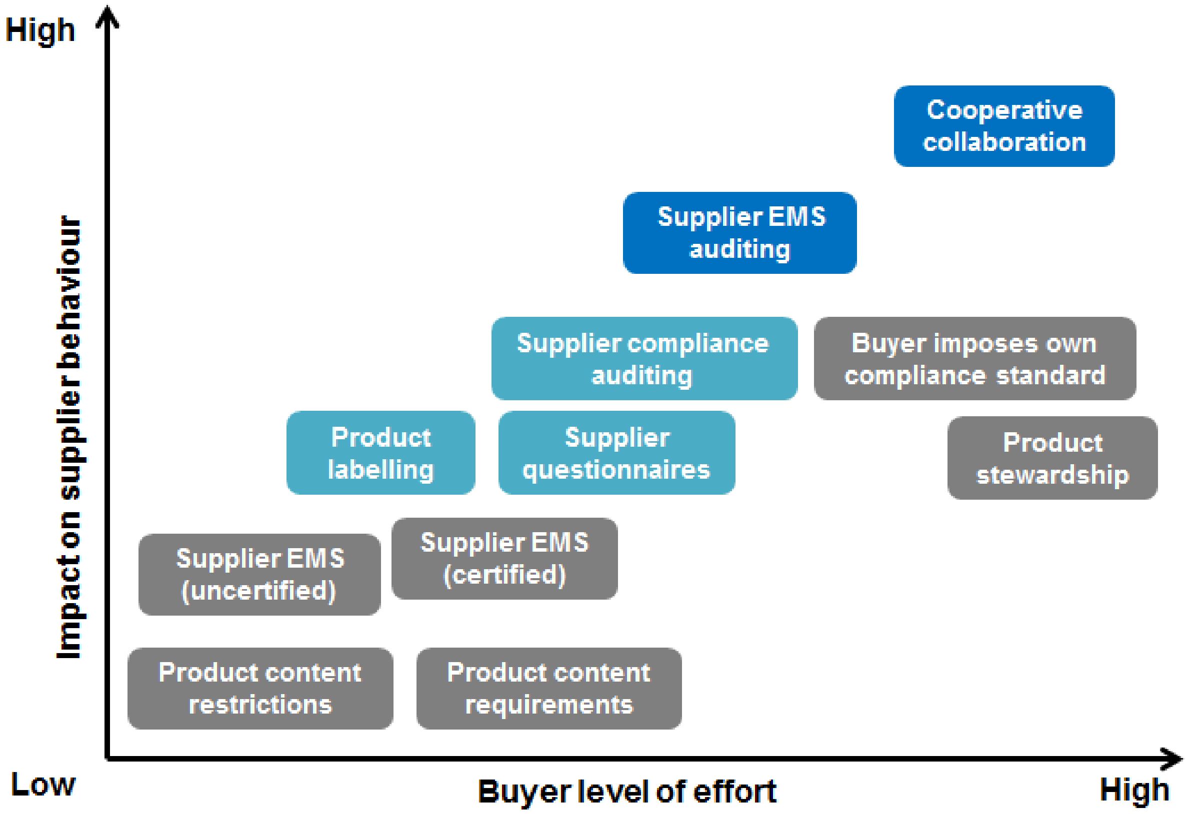
3.3.3.1 Description

An environmental quality scheme for suppliers can consist of several elements that complement each other, as illustrated in Figure 3-11. In general it can be seen that there is a correlation between the effort required by buyers and the environmental benefits (effect on suppliers). The very best results are obtained when:

- Suppliers are required to have an environmental management system (EMS), and this EMS is audited as part of the agreement;
- The schemes involve a high level of cooperation and collaboration with suppliers, which is also especially important to generate buy-in and ensure the success of the scheme.

Product labelling, supplier compliance auditing and supplier questionnaires are also useful supporting measures that require lower levels of buyer effort, and will be discussed where relevant. However, the main focus of this BEMP is on the aspects that have the highest impact on supplier performance.

Figure 3-11: Environmental quality standards – strategies for buyers



Source: Adapted from (Hamner, 2006)

The most ambitious strategies that have been implemented by major OEMs include the following aspects:

- **Requirement for suppliers to have certified environmental management systems:** Such as ISO 14001 and EMAS in order to qualify for purchasing agreements (Daimler, 2012), (Volkswagen, 2009), (Ford, 2012), (Toyota, 2010). The requirement alone is not enough to guarantee environmental performance improvements, but is a first step that must be implemented and audited later on.
- **Set environmental improvement goals and collaborate with suppliers on how to achieve them:** Targets in various environmental areas are set or agreed in collaboration with the buyer – for example, some manufacturers clearly request their suppliers to consider how to:
    - **Reduce waste and increase recycling:**
        - Renault-Nissan demands that its suppliers comply with its standard on “design for recycling”. This obliges the suppliers to propose recycled materials in the event of new applications of new materials or composite materials, and to back up the recyclability aspect of any products.
        - Toyota specifies that suppliers should work to reduce the volume of waste generated in their business activities, and requires that all individual and logistics packaging used must be recyclable, and that the weight and use of packaging must be minimised (Toyota, 2010);
    - **Reduce energy consumption and CO_2 emissions:**
        - Several manufacturers specify that suppliers should work to reduce their own CO_2 emissions (Toyota, 2010), (Volkswagen, 2009). This aspect is also supported by requiring that suppliers implement an EMS;
    - **Increase the use of sustainable materials:**
        - For example, at Ford, many commodity purchasing plans list recycled-content materials as a preferred material option, including those for battery trays, battery shields and wheel arch liners. In addition, the use of recycled plastics in required for underbody and aerodynamic shields, fender liners, splash

shields, stone pecking cuffs and radiator air deflector shields manufactured in North America. (Ford, 2012);

- **Reduce or eliminate the use of certain chemicals:**
  - Toyota's suppliers must completely eliminate the use of the four substances of concern (lead, cadmium, mercury and hexavalent chromium), and carry out audits to ensure that products supplied to Toyota do not contain any of these four substances (Toyota, 2010).
- **Improve biodiversity:**
  - Few automotive manufacturers currently include criteria to take into account biodiversity-relevant sustainability (e.g. participation in the development of sustainability labels, sourcing of metals from certified mining sites) The ecological impact of raw materials can be substantial, particularly for resources such as leather, rubber, minerals and metals (Global Nature Fund, 2013)

- **Supplier development:** These supportive measures are important in order to encourage greater awareness and compliance, as well as to cultivate better supplier relations:
  - Suppliers are typically required to complete a self-assessment questionnaire to determine their current status and are also required to communicate the standards to their own suppliers;
  - Training and support is provided either in face-to-face settings or via online portals;
  - Recognising supplier performance through environmental awards.
- **Monitoring and enforcement:** Auditing is an important part of the process, particularly for supplier EMS, but also for compliance with targets and other criteria. The most advanced schemes use third-party verification to monitor compliance. Requiring that suppliers report environmental data is also needed to maintain ongoing adherence to environmental quality standards, as well as to measure the impact. It may also be useful to identify potential problem areas and work with the supplier to resolve them.

3.3.3.2 Achieved environmental benefits

The environmental benefit of requiring suppliers to comply with certain standards depends on the stringency of the standards, the scope of suppliers covered and the resulting improvement in performance. Thus, requiring suppliers to report environmental data is necessary to precisely calculate the benefits. Of relevance here is the introduction of the new ISO 14001 standard (expected in 2015), which will significantly increase the requirements, particularly around reporting and robustness of data.

Examples of the environmental benefits achieved are outlined in Table 3-15:

Table 3-15: Examples of environmental benefits achieved in the supply chain

Environmental targets	Example achievement
Reducing waste and increasing recycling	A long-run partnership between Renault and their first tier suppliers has been established to ensure the economic viability of ELV and components recycling (de Medina et al, 2007). Recyclable materials are selected as a priority during vehicle design, including plastics and metals. In addition, the Renault-Nissan ECO$_2$ range of vehicles must contain over 7% of plastic obtained from recycling channels (Renault Nissan, 2011).
Reducing energy consumption	Toyota has shared their energy treasure hunt process with 180 tier one suppliers since 2008. The process has helped to identify annual energy savings of over 43.5 million kilowatt-hours - equivalent to 15,200 tonnes of CO_2 per year (Toyota, 2013). Fiat estimate that their suppliers have reduced their CO_2-equivalent emissions by around 39 million tonnes in 2012, saving around €325 million (Fiat - personal comm., 2014).

Environmental targets	Example achievement
Increasing the use of sustainable materials	In collaboration with their supplier partner Recycled Polymeric Materials (RPM), Ford launched a range of seals and gaskets that incorporate both 17% bio-renewable soybean oils and 25% post-consumer, recycled tyres. This material is currently used in 11 vehicle lines. In total, the seals and gaskets have removed more than 1,675 tonnes of weight from the vehicles. The use of post-consumer tyres in these gaskets and seals reportedly diverts 250,000 used tyres from landfills (Ford, 2012).
Reducing or eliminating the use of certain chemicals	Toyota promotes initiatives to stay ahead of EU legislation with regard to the management of substances of concern (lead, cadmium, mercury and hexavalent chromium), even in regions where these EU regulations do not apply. Suppliers must completely eliminate the use of the four substances of concern (Toyota, 2010).

As suggested by the range of examples detailed above, there are many different environmental pressures within the supply chain. It is important to note that these may vary depending on the supplier, product/service or geographical location. Some aspects may require particular attention, support or monitoring - for example, biodiversity impacts are typically more challenging to measure and verify.

It is likely that there is still significant scope to improve environmental performance of suppliers, particularly those located in geographic regions that have less stringent environmental regulations. On the other hand, encouraging uptake and compliance in these regions is typically more challenging (Hamner, 2006). Additional environmental benefits may be achieved beyond those that are explicitly required or encouraged. Several buyers recognise innovative suppliers through industry awards and learning platforms to facilitate sharing of best practices. For example, Toyota's Green Supplier Guidelines “emphasise that Toyota expects its suppliers to be in compliance with applicable laws, regulations and social norms. Suppliers are also asked to go beyond legal and social requirements and to undertake activities that support Toyota's environmental goals” (Zafarzadeh et al, 2012).

3.3.3.3 Environmental indicators

General environmental indicators should be used to monitor the effectiveness of the scheme in terms of the general take-up among suppliers, as follows:

- Percentage of suppliers (by number or by purchasing budget/value) that comply with required standards according to internal or external audits;
- Percentage of suppliers that flow down requirements to their own suppliers.

Specific performance improvements achieved in the supply chain should be defined according to the environmental objectives of the scheme (e.g. emissions/waste per unit of product). Appropriate indicators are suggested in *Section 3.3.2: Design for sustainability using Life Cycle Analysis (LCA).*

3.3.3.4 Cross-media effects

It is likely that a strong focus on only a limited number of environmental aspects will lead to trade-offs in other areas. Therefore, best practice supply chain management systems incorporate a broad range of environmental issues considered on a lifecycle basis to mitigate against this risk.

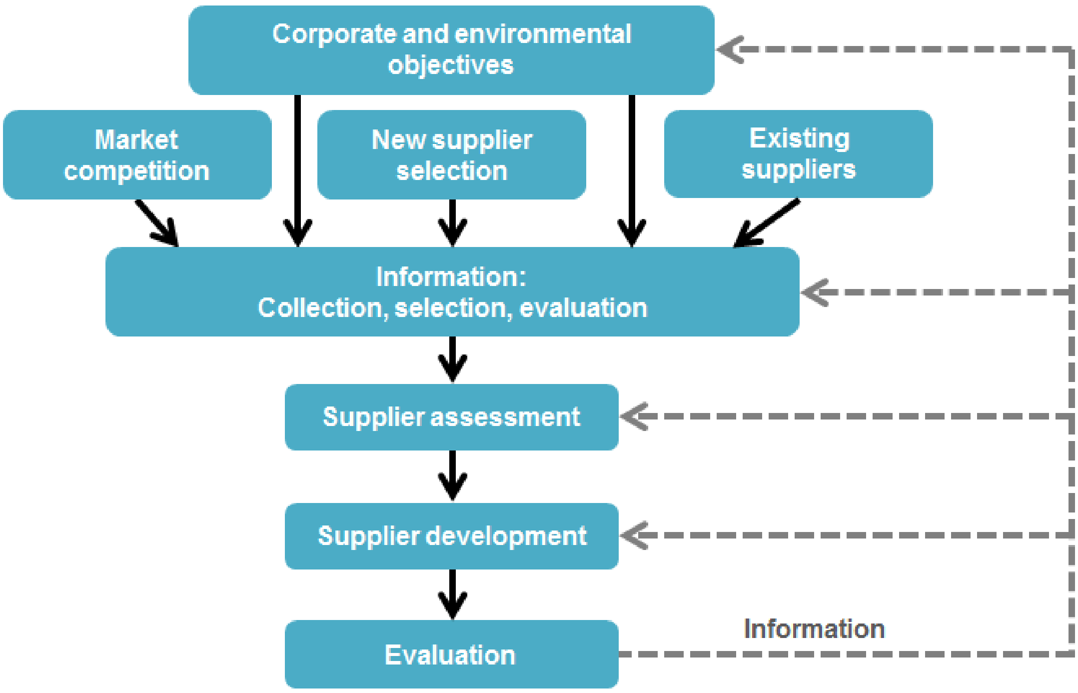
For example, some manufacturers have started to encourage purchasing from more local suppliers in order to avoid long-distance transport and the associated environmental impacts, as well as to support the local economy. However, such decisions should be considered from a life-cycle perspective (see *Section 3.3.2: Design for sustainability using Life Cycle Analysis (LCA)*), since local production is not necessarily the most environmentally efficient option.

3.3.3.5 Operational data

Figure 3-12 shows a framework for purchasers to implement environmental quality standards into supply chain management.

- The first step is to **develop environmental responsibility requirements** for suppliers and accompanying guidelines. These are typically based on corporate and environmental objectives, and may draw from internationally recognised initiatives such as ISO 14001 and the Global Reporting Initiative. The requirements may be introduced to the suppliers over time. For example, suppliers may initially be asked to comply on a voluntary basis, or the requirements may be introduced for contracts with new suppliers only. Eventually, the aim should be for all suppliers to comply with the standards on a mandatory basis by incorporating them into contractual documents and purchasing decisions.
- **Supplier assessment** involves the measurement of the environmental practices of the supplier, such as ISO 14001 certification, involvement in pollution-prevention and waste-reduction programmes and meeting of environmental performance targets. As a first check, supplier self-assessment questionnaires are appropriate. An industry-developed questionnaire covering environmental issues as well as wider societal aspects has been developed by the European Automotive Group on Supply Chain Sustainability – available for download online[16] (CSR Europe, 2014). More detailed checks are recommended for high risk and significant suppliers.
- **Supplier development strategies** such as training are provided on an ongoing basis. Where suppliers do not satisfy the requirements, additional supplier development activities may be needed. Supplier performance problems can be technical or managerial, and suppliers should be invited to participate in the analysis of the problems so that a development plan can be implemented.
- The **evaluation** step is used to measure the results of the programme and to ensure continuous improvement.

Figure 3-12: Framework for implementing, selecting and developing environmental requirements into the supply chain



Source: Adapted from (Stroufe, 2006)

[16] http://www.csreurope.org/sites/default/files/CSR%20SAQ%20automotive%20sector.pdf

In general, it is recognised that developing a closer relationship with suppliers (e.g. through supplier development activities) is beneficial both for environmental outcomes of projects and as a facilitator for environmental objectives (Zafarzadeh et al, 2012). For the automotive industry in particular, this aspect is highly important – whereas many other industries can quickly improve supply chain sustainability by switching suppliers, many key components and materials used in automotive manufacturing are sourced from suppliers with whom long-term arrangements are set up, or from highly specialised organisations. An example of close cooperation between suppliers and manufacturers to achieve an environmental goal is outlined in Box 3-4.

Box 3-4: Case study: Supplier development activities to eliminate substances of concern

In aiming to eliminate substances of concern (lead, mercury, cadmium and hexavalent chromium), Toyota recognised that it is difficult for parts suppliers to independently establish a schedule for switching to hexavalent chromium free products. Toyota therefore:

- Set objectives in line with responses in other industries such as materials, plating processing, and fasteners;
- Five leading suppliers actively coordinated their activities and produced guidelines for schedules for switching to hexavalent chromium free products;
- In accordance with these guidelines, fastener and plating processing manufacturers presented switchover schedules for each product line, and suppliers confirmed that there were no problems with the schedules. In those instances where there were problems, coordination meetings were held for each product type;
- Toyota had suppliers conduct voluntary audits beginning in June based on a check sheet that it created, and then obtained reports on the results. In addition, the items on the check sheet were confirmed through audits at the processing sites of 130 key suppliers. Requests for immediate corrective actions were made to those suppliers whose responses were found to be lagging.

Toyota has produced several vehicles that are completely free of the substances of concern, and their use was eliminated at major overseas plants by the end of 2007.

Source: (Toyota, 2005), (Toyota, 2014)

In terms of enforcement, processes must be put in place to deal with suppliers that have violated the applicable sustainability criteria or are suspected of doing so. For example, Daimler requests the supplier to respond and to describe any measures that have been taken to remedy the situation (Daimler, 2012). In extreme cases, the partnership is terminated. Similar procedures have also been adopted by other OEMs such as Ford (Ford, 2012) and Renault (Renault, 2012).

3.3.3.6 Applicability

Many organisations require all of their suppliers to agree to the same general environmental code of conduct that is integrated into purchasing agreements. More stringent standards generally apply to suppliers depending on their share of total purchasing budget and/or the specific types of products or services they supply (e.g. different requirements for component suppliers, raw materials, equipment, facility services and logistics.

Initially it may be beneficial to concentrate on suppliers that represent the largest share of total purchasing budget or those with high environmental impacts. Auditing of suppliers requires a significant effort that appears feasible only for larger organisations that already practice close inspection of supplier operations (Stroufe, 2006). In the longer term the requirements can be rolled out to more suppliers.

The effectiveness of such schemes tends to be enhanced in cases where the buyer has significant market power and/or close relationships with the suppliers in question (Stroufe, 2006).

3.3.3.7 Economics

Auditing and enforcing new environmental requirements, as well as carrying out supplier development activities is likely to incur costs – particularly since OEMs typically have thousands of individual

suppliers. In the competitive automotive industry, the economic implications both to buyers (manufacturers) as well as their suppliers are relevant. Table 3-16 gives an indication of costs to buyers and suppliers from activities related to environmental management in the supply chain.

Table 3-16: High level overview of costs to buyers and suppliers arising from environmental management in the supply chain

	Cost to buyers	Cost to suppliers
Requiring suppliers to have an environmental management system (EMS)	The cost to buyers of implementing environmental requirements is thought to be low, as they can introduce this requirement to suppliers based on existing accepted standards such as ISO 14001 or EMAS (Hamner, 2006)	The cost to suppliers varies depending on the size of the organisation and the standards of management already in place. In general, the cost is higher if they have to develop an environmental management system where they do not already have one (Stroufe, 2006) – for example, first year certification costs for EMAS range from €35,800 to €66,800 for manufacturing firms (Milieu et al, 2009).
Auditing supplier compliance	Costs for external audits depend on the size and complexity of the organisation – an expert estimates this to be around five to seven days for a senior auditor at consultancy rates of up to €1,150 (Drury - personal comm., 2014). External audits can combine wider aspects (health, safety, quality etc.) in order to reduce the overhead costs.	To ensure that they pass the audit, continued effort is required from suppliers to comply with the standards. For example, estimated annual costs for EMAS compliance range from €16,900 to €34,200 annually (although this cost may be offset by energy savings) (Milieu et al, 2009).
Supplier development	Costs to provide training to automotive suppliers can vary depending on the ambition of the scheme; for the best results it is important to embed the training in the day-to-day practices of the organisation, since one of the key challenges to improving environmental performance is staff engagement (Drury - personal comm., 2014)	Typically, supplier training is paid for by the buyer, but firms may also choose to invest in their own training and development.

Notes: actual costs will vary significantly depending on the scheme and the organisations involved.

These costs can be limited by:

- Focussing on high impact and high risk areas of the supply chain first;
- Conducting some audits using internal experts rather than third-party suppliers;
- Rotating audits so that suppliers are audited on a multi-year basis (e.g. every three years).

3.3.3.8 Driving force for implementation

Environmental practices are increasingly important throughout the supply chain due to the need to comply with regulatory pressures, economic advantages of reducing waste and its associated costs, and also in response to customer expectations with respect to reducing emissions and increasing recycling (Stroufe, 2006). Sustainability and social responsibility are increasingly recognised as ways to strengthen brand names or differentiate products (Zafarzadeh et al, 2012).

3.3.3.9 Reference organisations

Suppliers are often encouraged to adopt certified environmental management systems, but only a few manufacturers formally require suppliers to have them, including Ford (ISO 14001), Daimler and Toyota (ISO 14001 or EMAS).

The extent of monitoring and enforcement activities also varies considerably. Frontrunner organisations verify compliance for a major proportion of their suppliers, compared to many other manufacturers that do not conduct formal assessments. For example:

- Third-party assessments of management of supplier groups were conducted on 387 of Renault's suppliers in 2011, who represent an amount equivalent to 68% of Renault revenue (Renault, 2012);
- Volkswagen have verified (using internal staff) environmental certification for 44% of their suppliers (based on volume) and a further 40% have completed self-assessments – bringing the total to 84% (Volkswagen, 2013).

In terms of training, several manufacturers have partnered with the Automotive Industry Action Group (AIAG) to deliver training collaboratively with other OEMs, while others deliver training online. For example, Volkswagen provides online training in eight languages to its suppliers, and suppliers must complete a self-check before the module is "passed". At the end of 2013, 8,652 tier one suppliers had successfully completed the E-learning module, equating to 50% of procurement volume (Volkswagen, 2013).

3.3.3.10 Reference literature

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3.4 Plant utilities & infrastructure

3.4.1 Section overview and technique portfolio

This section covers the operational factors relating to a particular plant, site or building as part of a wider organisational strategy. This includes the management of its facilities, decisions on design features and maintenance. Since the stock of existing manufacturing plants is significant, this section includes techniques that are applicable to existing buildings as well as those in the design stages.

The plant utilities and infrastructure refers to the buildings, facilities and services of a particular manufacturing site. The best practices described in this section are typically more location-specific than the cross-cutting measures outlined in *Section 3.3: Cross-cutting operational best environmental management practices*.

The design of new plants can be optimised to ensure that energy is saved in the operation of the plant during its lifetime. For example, Toyota's plant in Valenciennes is relatively compact, comprising a single building, covering 17 hectares (the whole site is only 233 hectares), which is laid out around a central point. This means that the energy cost of heating, as well as transport around the site, is 30% less than a comparative plant (by output) (Toyota, personal comm., 2014). The general approaches to minimising environmental impacts of construction and buildings are outlined in other guidance, as shown in Box 3-5.

Box 3-5: General building management best practice provided in other existing guidance

The **Sectoral Reference Document on Best Environmental Management Practices for the Construction Sector** (European Commission, 2012). These include:

- Land use planning;
- General building design;
- Construction products;
- Construction and refurbishment;
- Building operation and maintenance;
- Building end-of-life.

Most of these techniques are also applicable to car manufacturing facilities without the need for specific tailoring. However, in some cases the specific characteristics of car manufacturing facilities mean that certain techniques can be particularly beneficial, or the general guidance can be modified to improve effectiveness. Therefore, this section provides details on the following processes for which additional sector-specific guidance could be beneficial:

- **Water recycling and rainwater harvesting:** This BEMP focusses on the re-use and recycling of water within an automotive plant – i.e. the reuse/recycling of water from production processes, as well as the use of alternative water sources.
- **Green roofs:** Car manufacturers are pursuing a wide range of green building operations - a notable aspect is the use of green roofs on several facilities, where they can help to manage stormwater runoff from large industrial manufacturing sites, reducing the burden on the sewer network and lowering water treatment costs.
- **Alternative energy sources:** The first priority must always be to reduce energy consumption as far as possible before considering fuel switching to a renewable source – see relevant guidance in *Section 3.5: Key manufacturing processes.* Once options for energy efficiency have been fully explored, renewable energy should be considered to reduce the emissions of the remaining demand.
- **Optimisation of lighting in automotive manufacturing plants:** Lighting can account for a significant proportion of electricity consumption at a car manufacturing plant and its optimisation can be among the cheapest energy-saving measures available. This BEMP

provides guidance on how to optimise lighting technologies and lighting levels specifically for car manufacturing plants.

- **Biodiversity management**: The focus of this section is therefore on direct impacts, where companies can directly affect biodiversity on their premises, although it is noted that significant impacts occur in the supply chain.

3.4.2 Water recycling and rainwater harvesting

SUMMARY OVERVIEW:				
The automotive industry is a large consumer of water, and therefore one of the key targets for wastewater reuse and recycling, as well as using alternative sources of water (i.e. rainwater). The general best practice principles aim to avoid/eliminate the use of high-quality water in processes where this is not necessary, as well as increase reuse and recycling to meet remaining needs.				
Relevant lifecycle stages				
Management	Design	Supply chain	**Manufacturing**	End-of-life
Main environmental benefits				
Energy consumption	Resource use and waste	**Water use & consumption**	Emissions to air, water, soil	Ecosystems & biodiversity
Environmental indicators				
• Installation of a wastewater recycling system that supplies internal or external water demand • Installation of a rainwater recycling system that supplies internal water demand • Quantity of rainwater and wastewater reused (m^3/yr)				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Water use strategy and management			
Related BEMPS	• Water-saving opportunities in automotive plants			

3.4.2.1 *Description*

After options to avoid and reduce water use in production have been exploited (see *Section 3.5.3: Water-saving opportunities in automotive plants)*, the remaining needs can often be met to a large extent through combinations of wastewater recycling and rainwater harvesting.

Wastewater recycling

Wastewater can be reused in other processes. The treatment required depends on the quality of the influent wastewater, and the required quality of the treated water. This in turn will depend on the quality required for the intended reuse activities. Recycling of water- (and oil-) based coolants is also widely achievable – including emulsions from drilling oil, oil from presses, washing and degreasing water and bleeding from cooling systems and compressors (Azpilicueta, 2013).

Wastewater recycling systems vary greatly in their complexity, size and treatment processes. Systems typically consist of (Environment Agency, 2010):

- A pre-treatment tank to collect water from;
- Some form of treatment system, with the sludge going to the foul drain and treated water to one or more treated water storage tanks;
- A pump to supply treated water to points of use.

Rainwater harvesting

Rainwater is collected and used in non-potable applications. Industrial and commercial premises generally have a greater demand for non-potable water. Since they typically have a large roof area, these buildings have the potential to recoup large amounts of rainwater. If it is correctly collected and stored it can be used for certain applications without further treatment – and typically presents fewer health risks compared to wastewater recycling (Zero Waste Scotland, 2012).

For rainwater harvesting systems, there are typically four main elements (European Commission, 2012):

- Catchment area, usually a roof surface or pavement;
- Conveyance system: piping and gutters transferring rainwater to the temporary water storage. Two different systems may be needed depending on the cleanliness of the catchment area;
- Storage device: usually a tank, which should be accessible and can be installed over the roof, within the building facilities or underground;
- Distribution system: this may consist of a container for the irrigation system, a piping system or water pumping devices.

Non-domestic wastewater recycling and rainwater harvesting systems normally have bespoke specifications. The pumps and tank can be optimised to suit the building size, height, water demands, treatment options and pipework design (Environment Agency, 2010).

3.4.2.2 Achieved environmental benefits

Providing an alternative source of water recovery and reuse can help reduce demand for mains water supply. In addition, it reduces the volume of water discharged into the sewerage system. Estimates of water savings from reuse, recycling and rainwater harvesting are shown in Table 3-17.

Table 3-17: Estimated water savings from reuse, recycling and alternative sources in the automotive industry

Type	Option	Approximate total water saving
Re-use	Reuse water from a critical rinse stage in a less critical rinse stage	💧💧 - 💧💧💧
Recycle	Treat site wastewater and recycle internally	💧💧 - 💧💧💧
Alternative sources	Rainwater harvesting	💧 - 💧💧

Notes: 💧 *= <5% total water saving;* 💧💧 *= 5 – 10% total water saving;* 💧💧💧 *= over 10% total water saving*

Source: (Ai group, 2009)

The quantity of water that can be reused and/or recycled is dependent on the level of treatment, which is directly related to the characteristics of the site effluent and the application required for the treated water (Defra, Ricardo-AEA, 2014). An overview of some common wastewater recycling technologies in industrial processes is given in Table 3-18.

Table 3-18: Typical water savings using different wastewater recycling technologies

Industrial application	Typical saving
Closed-loop recycling	90%
Closed-loop recycling with treatment	60%
Automatic shut-off	15%
Counter current rinsing	40%
Reuse of wash water	50%

Source: Adapted from (Zero Waste Scotland, 2012)

Illustrative case study examples of the environmental achievements at automotive plants are described in Table 3-19.

Table 3-19: Case study examples of water reuse, recycling and rainwater harvesting at automotive plants

Manufacturer & site	System	Water savings	Source
Ford Maraimalai Nagar (India)	Wastewater from the assembly and engine plants are each pre-treated then mixed with sanitary and cafeteria wastewaters. After biological treatment, the combined stream is filtered through active carbon and then ultrafiltration. The final stream is then sent to a three-stage reverse osmosis system, which leaves a large volume of salt-free water as well as a small volume of concentrated brine. The final part of the process sees the water in the brine boiled, condensed and reused in the plant, with only a solid salt remaining	According to Ford, these activities mean that the plant has the lowest water requirement of any of its major global facilities – 1.16m^3 of water use per vehicle	(Brooks, 2012)
GM San Luis Potosí plant (Mexico)	The wastewater contains high concentrations of dissolved metals, phosphates, free and emulsified oils, dissolved organics and silica. Veolia Water Solutions OPUS™ Technology was used, as well as a double-pass reverse osmosis to produce deionized water for the plant's paint operations	Zero liquid discharge – 90% of wastewater in the plant operations is cleaned and reused, thus minimising the volume of liquid waste (<10%) generated for evaporation in solar ponds. This significantly reduces the amount of groundwater used, saving around 1.2 m^3 water per vehicle built	(General Motors, 2013), (WaterWorld, 2014)
Volkswagen Salzgitter (Germany)	Recycled water is treated and used, for example, in the production of emulsions. Thus, in the engine plant, an evaporator system is used to extract most of the water from oily wastewater. Once separated, the condensate can be used in its entirety to produce new emulsions and detergents. The remaining oil concentrate is either used as lubricating oil, or thermally recycled in the site's power plant	The site treats all its industrial wastewater and recycles it completely. This has led to annual water savings of around 30,000 m^3	(Volkswagen, 2013).
Toyota Valenciennes (France)	Rainwater collection system built in 2008 with a capacity of 6,209m^3 After this, a second 10,385 m^3 tank was built in August 2012 Rainwater is collected as run-off from the impermeable parking lot for use in the manufacturing processes. TMMF achieved zero consumption of industrial water for a period of six months in 2013, however on average usage is: • 42% industrial water • 37% rainwater • 21% recycled water	Water savings of 36% of the plant's normal use from the first system. The second system aims to make Toyota fully autonomous in its industrial water supply	(Toyota, 2012a); (Toyota, 2012b) (Toyota - personal comm., 2014)

Manufacturer & site	System	Water savings	Source
Gestamp Navarra (Spain)	In 2013, a new wastewater treatment plant was implemented to tackle discharges from drilling/pressing, cooling systems and compressors. It treats 650m^3 water each year, of which 500m^3 are recovered and used for washing floors in the plant and 100m^3 of waste oils are sold to the waste management service provider and an economic return is obtained. It also produces 50 m^3 of oily sludge, from which 10 to 20% of concentrated waste can be obtained so that it can be removed by the authorised waste management service provider	The actual volume of hazardous discharges that must be treated via an authorised waste management service provider has decreased significantly. This has led to cost saving and a reduction in water footprint.	(Azpilicueta, 2013)

3.4.2.3 Environmental indicators

The most relevant indicators of water recycling implementation are (European Commission, 2012):

- Installation of a rainwater recycling system that supplies internal water demand;
- Installation of a wastewater recycling system that supplies internal or external water demand;
- Quantity of rainwater and grey water reused (m^3/yr);
- Percentage of annual potable water consumption substituted with recycled rain- or wastewater.

Since the performance of these systems depends on a number of important factors, the proposed benchmark is (European Commission, 2012):

- Installation of a rainwater recycling system that supplies **internal** water demand;
- Installation of a wastewater recycling system that supplies **internal or external** water demand (when connection to community networks is available).

Further environmental indictors are suggested in (European Commission, 2012).

3.4.2.4 Cross-media effects

While in general, cross-media effects should be limited if systems are implemented properly, it is worth noting potential issues.

Reused rain water can have a higher energy and carbon footprint than mains supply water due to the pumping requirements – i.e. electricity to run pumps and control systems – and embodied carbon in system materials (European Commission, 2012), (Environment Agency, 2010). Furthermore, rainwater reuse systems essentially bypass the natural water cycle. This could exacerbate water stress in regions where groundwater levels are locally declining and where water is supplied from a (nearby) area with greater water availability. However, such situations are rare (European Commission, 2012). Conversely, widespread rainwater harvesting could reduce flooding risk during high rainfall events (European Commission, 2012).

Moving from one treatment technology to another may have trade-offs. For example, BMW reports that by moving from an ion exchange technology to reverse osmosis to desalinate water, they increased their water use but reduced the chemicals required (BMW, 2012).

3.4.2.5 Operational data

Water and wastewater mapping, as well as providing an indication of the required water quality by department or process, can allow organisations to match up wastewaters with reuse opportunities. In some cases, process water discharges can be used in other processes without any treatment provided the reused water does not impact quality and still complies with regulatory requirements. However, in most cases, wastewater requires some filtration and disinfection to prevent microbial

growth and fouling of pipework (Zero Waste Scotland, 2012). Suitable reuse applications in the car manufacturing sector include:

- **Cooling water.** The significant requirement for cooling water in the industrial production of automobiles means that there is also considerable potential for water savings in this area (Volkswagen, 2013). Water of potable quality is not required for the purpose of cooling. Treated wastewater can be recirculated from other areas, and combined with heat exchangers to minimise the water used;
- **Non-crop irrigation.** For example, watering green areas or in conjunction with green roofs (see *Section 3.4.3: Green roofs*).
- **Toilet and urinal flushing**
- **Vehicle/component washing**

To ensure recycled and harvested rainwater is suitable for reuse, bacterial growth must be controlled. This can be dealt with using three main approaches (Zero Waste Scotland, 2012):

- Limit the time that the water is stored;
- Use chemical disinfectants such as chlorine or bromine to inhibit bacteria growth and extend the possible storage time;
- Treat water using traditional biological methods or newer membrane filtration technology.

Most components of a rainwater harvesting system require annual checks (maintenance of the pump, cleaning the roof, gutters, etc.) and cleaning of the tank ("desludging") every three years (Environment Agency, 2010).

Additional general guidance is provided in the **Sectoral Reference Document for Best Environmental Management in the Construction Sector** (European Commission, 2012).

3.4.2.6 Applicability

Water recycling systems can be designed into all new buildings. Retrofitting to existing buildings is expensive and may be impractical unless the building is undergoing extensive renovation (European Commission, 2012). The economic feasibility of rainwater harvesting systems is also highly dependent on the climate (European Commission, 2012).

Systems are more effective where (WRAP, 2010):

- The quality of recycled water is appropriate to its use (so that treatment is minimised);
- The volume produced is similar to the volume used (to minimise issues with storage);
- The water distribution systems are compact with little horizontal distribution, e.g. multi-storey office buildings with vertically stacked washrooms;
- Rainwater systems are typically most cost-effective on buildings with large roof areas but relatively densely-packed service cores.

The potential for a rainwater harvesting system is also affected by the potential for storage in close proximity to the plant. The cost of implementation (including the cost of pumping and digging trenches) rises rapidly as the distance between the water reservoir and the manufacturing facility increases. Indeed, at Toyota's plant in Valenciennes, it was found to be cheaper to build a new reservoir near to the plant, than to use an existing reservoir just a few kilometres from the plant (Toyota - personal comm., 2014).

Water quality is also a significant factor. There must be a reasonably consistent use of water, as changes to processes inside and outside the manufacturing plant can lead to changes in water quality. Therefore it is critical to understand how new or modified processes (e.g. the introduction of a new sealant on the production line) impact water treatment decisions. For example, at Toyota's plant in Valenciennes the car park is used to collect rainwater. When salt was used to de-ice the tarmac, the wastewater treatment processes had to be adapted to cater for new chemical composition of the collected rainwater (Toyota - personal comm., 2014).

There are also legislative requirements which could increase the cost of construction. For instance, are separate piping systems required to separate water of varying qualities (Toyota - personal comm., 2014)

3.4.2.7 Economics

Due to the variability of water recycling solutions, which are tailored to the specific needs of each site, the costs and savings are difficult to quantify. Approximate ranges are provided in Table 3-20.

Table 3-20: Water saving options in the automotive industry

Type	Option	Approximate option cost
Re-use	Reuse water from a critical rinse stage in a less critical rinse stage	Medium - High
Recycle	Treat site wastewater and recycle internally	Medium - High
Alternative sources	Rainwater harvesting	Medium - High

Notes: Low cost = up to €10k; Medium cost = between €10k to €100k; High cost = over €100k

Source: (Ai group, 2009)

Water recycling systems can be installed at relatively low cost during construction, and at reasonable cost during major renovations; however they are expensive to retrofit (European Commission, 2012). The reuse of wastewater is more cost-effective for larger sites due to the economies of scale (Zero Waste Scotland, 2012).

For rainwater harvesting, where large collection areas can be exploited and only a low quality of water is required, commercial installations can pay back the investment cost in as little as two to three years (Zero Waste Scotland, 2012). It is more expensive to retrofit rainwater harvesting systems than to invest in technology when the site drainage system is under construction.

As a concrete example of an application in the automotive industry, key cost and performance metrics from the rainwater collection system at Toyota France are as follows (Toyota, 2012a):

- Water treatment costs (including labour, energy, chemicals and filters);
  - Recycled water (coming from rain water and wastewater treatment discharge water) are around 0.25 €/m^3;
  - Industrial water (coming from city network): around 0.75 €/m^3;
- Cost of rainwater collection system:
  - The cost of the first reservoir (6,209m^3) was €224,000, with an additional €23,000 contributed by the French Water Agency (Toyota - personal comm., 2014).
  - The cost of second reservoir (10,385m^3) was €157,000, with an additional €43,000 from the French Water Agency (Toyota - personal comm., 2014).
- Expected payback period: two years;
- Actual payback period: four years (due to decreased production and lower rainfall).

3.4.2.8 Driving force for implementation

The two primary objectives for implementing water recycling schemes are to reduce water consumption and to reduce wastewater volume (European Commission, 2012). Increasingly, national regulations are encouraging the installation of water recycling systems and provide financial incentives for their installation. This includes international legislation – for example, in most Indian states, the relevant authorities require manufacturers to achieve zero liquid discharge in their operations – one of the key drivers for the high performance of the Ford Maraimalai Nagar plant (Brooks, 2012).

3.4.2.9 Reference organisations

Wastewater recycling systems are used in most plants to some extent. For example, many Volkswagen sites have treatment plants with membrane or evaporative reactors, allowing the bulk of process water to be reused. In these plants, more than 95% of the water remains in the cycle, or else is used for cooling, toilet flushing and irrigation (Volkswagen, 2013).

Rainwater harvesting systems have been implemented by several manufacturers at selected sites, including:

- Fiat – Michigan engine plant, USA (Fiat, 2012);
- Toyota Onnaing (France) - (Toyota, 2012b).

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3.4.3 Green roofs

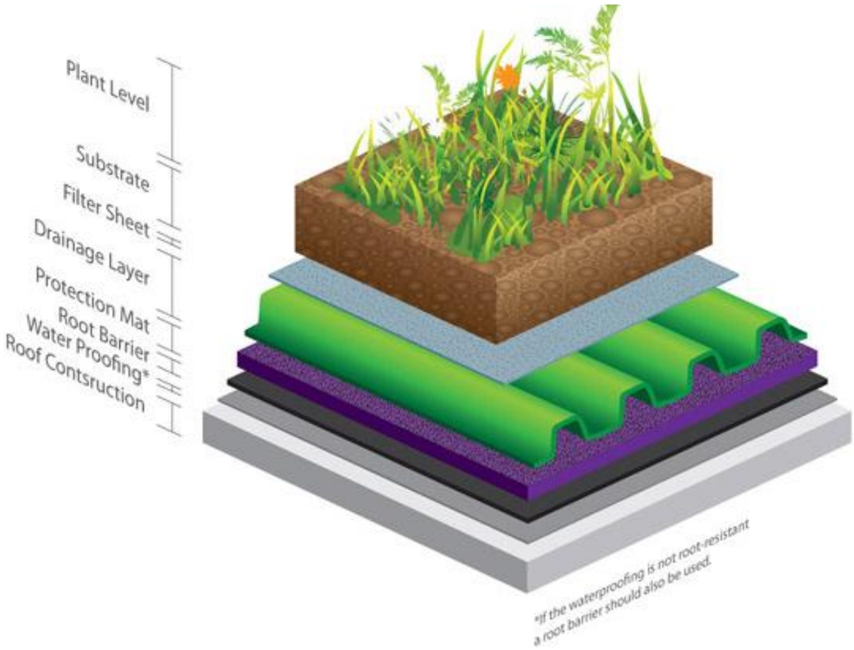
SUMMARY OVERVIEW:				
Green roofs can offer environmental benefits in several different areas depending on the site and design. Best practice organisations have retrofitted green roofs across some of their industrial sites, particularly in environmentally sensitive areas where management of stormwater runoff is important.				
Relevant lifecycle stages				
Management	Design	Supply chain	**Manufacturing**	End-of-life
Main environmental benefits				
Energy consumption	Resource use and waste	Water use & consumption	**Emissions to air, water, soil**	**Ecosystems & biodiversity**
Environmental indicators				
• % coverage of sites that are suitable for green roofs (suitability depending on structural aspects, access to sunlight, moisture, waterproofing, and drainage or water storage systems)				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	**N/A**			
Related BEMPS	• Biodiversity management			

3.4.3.1 Description

"Green" or "living" roofs are layers of living vegetation installed on top of buildings. They can help to manage stormwater runoff, reducing the burden on the sewer network and lowering water treatment costs (GRO, 2011). In addition, water quality is improved due to retention and filtration through the plant's soil and root uptake. They can also help to insulate the building, reducing cooling and heating costs.

Figure 3-13 shows a common green roof structure. Sedums are the most widely-used plants for green roofs since they are drought-resistant and able to grow in shallow soil. However, the potential range of plants that could be used is very wide.

Figure 3-13: Typical green roof structure



Source: (Groundwork Sheffield, 2011)

3.4.3.2 Achieved environmental benefits

The mitigation of stormwater runoff is often the primary environmental benefit, because rapid roof runoff in areas with impervious surfaces such as large automotive production sites can result in flooding. Each installation is unique, and the environmental performance varies by region, climate, building and roof design.

Table 3-21 illustrates different environmental objectives possible, and the design features that can best contribute to each aim. The achievements of a specific example in the car manufacturing sector are also outlined. This is based on an extensive green roof that was retrofitted at Ford Motor Company's River Rouge Plant (USA). Around 42,000m^2 of assembly plant roofing has been covered with sedum and other succulent plants since 2003 (Priddle, 2013).

Table 3-21: Suitable roof designs for desired environmental objectives

Environmental objective	Typical results	Automotive industry example (Ford River Rouge)	Suitable roof design features to optimise each objective
Water attenuation	Depending on the plants and depth of growing medium, green roofs retain 70-90% of the precipitation that falls on them; in winter they retain between 25-40%	The green roof has reduced runoff by 42%	Reservoir / drainage board with water holding capacity and unrestricted water escape from roof for excess water.
Increase roof lifespan (reduce material consumption)	On average, a green roof could prolong the life of a conventional roof by at least 20 years because the vegetation prevents the roof from being exposed to ultraviolet radiation and cold winds	The roof at Ford is over ten years old and nothing has needed replacing thus far	Double skin exposed waterproofing

Environmental objective	Typical results	Automotive industry example (Ford River Rouge)	Suitable roof design features to optimise each objective
Cooling effect (reduce HVAC energy consumption)	The temperature regulating properties of green roofs, can reduce heating and cooling demands. An extensive green roof can reduce the daily energy demand for air conditioning in the summer by over 75%	The roof at Ford insulates the building – lowering the amount of heat entering the plant by 70% and reducing heating and cooling costs by up to 5%	High level of vegetation coverage with varied types and heights of plants
Biodiversity	By providing food, habitat, nesting opportunities or resting places Different types of green roofs and different types of substrate and vegetation will support different habitats and species. Biodiverse roofs can be designed to mimic various habitats.	The roof is home to more than 35 species of insects, spiders and birds, including Canada geese	Varied depths of substrate, types and heights of plants, , and the inclusion of "natural features"
Improve water quality	Reduction in cadmium, copper and lead in runoff by over 95% compared to conventional roof systems. Zinc levels in runoff may also be reduced 16% compared to conventional roof systems	Water runoff contains 85% fewer suspended solids	Specific substrates and minerals can be used to filter out specific elements

Notes: In all cases, the substrate depth should be at least 80mm, and ideally deeper intensive systems with depths of greater than 200mm should be used where possible.

Source: Adapted from (Groundwork Sheffield, 2011), (GRO, 2011) , (Greenroofs.org, 2014), (Chicago, 2014) and (Priddle, 2013).

3.4.3.3 Environmental indicators

The potential level of uptake depends on the suitability of the facility – not all sites will necessarily benefit from green roofs. A suitable indicator should therefore be measured relative to the number of suitable sites with green roofs (% coverage).

Systems can be monitored in terms of their performance depending on the design objectives. For example:

- Water holding: % retention, water run off (m^3);
- Water quality: pH, temperature, total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), chemical oxygen demand (COD), and nutrients (ammonia, nitrite, nitrate, phosphate, and total phosphorus);
- Cooling effect: reduction in energy demand for HVAC (MJ);
- Qualitative biodiversity indicators (e.g. number of species living in the roof).

3.4.3.4 Cross-media effects

Specific measures designed to benefit biodiversity may affect the appearance of the roof, or could change the performance of the roof in terms of rainwater attenuation or cooling (Groundwork Sheffield, 2011).

3.4.3.5 Operational data

Key considerations for implementing green roofs include the structural and load-bearing capacity of the building, access to sunlight, moisture, waterproofing, and drainage or water storage systems. Most extensive roofs, and many intensive green roofs, are supplied as complete systems, which include all components for green roof construction from the insulation and waterproofing membrane to specialist soil mixes and vegetation (Groundwork Sheffield, 2011). Detailed engineering guidance is available in (GRO, 2011).

There are a wide range of choices with respect to vegetation, but the most common are sedum mats – for further design information, please refer to (GRO, 2011).

Extensive systems (<100mm) typically do not require much maintenance after establishment. Irrigation should not be required, fertilisation is only needed on an annual basis, removal of weeds and other undesirable plant species is needed only once or twice a year (GRO, 2011). Conversely, extensive systems require regular irrigation, fertilisation and management (GRO, 2011).

3.4.3.6 Applicability

Green roofs are applicable to many existing and new building designs. However, the load-bearing capacity of existing roofs must be taken into account when retrofitting systems (Chicago, 2014). They are most suitable for flat roofs, as there are additional costs associated with erosion control for sloped roofs (Groundwork Sheffield, 2011). Limitations may apply in cases where the roof shape of existing installations is not suitable, and in some cases due to local climate/weather conditions (Fiat - personal comm., 2014). Limitations may also apply in instances where production sites have systems with pipes that are installed under the roof, such as a sprinkler system or central coolant system, as well as possible installations on the roof for ventialation or cooling (Schleicher – personal comm., 2014). In all cases, a structural assessment should be conducted.

Both solar thermal and solar photovoltaic (PV) panels can be combined effectively with green roofs. Indeed, the cooling effect of a green roof can lead to performance improvements from a PV system mounted on A-frames, as the cells work at a higher efficiency. The area under any panels will be shaded from sun and will not be naturally watered - the effect will be to create a different microclimate and attract different (especially shade-loving) plants (Groundwork Sheffield, 2011).

Storm-water runoff from a green roof is reduced compared to a traditional roof. However, rainwater can still be collected and used for any non-potable applications. In this case, fertilisers should not be used as high nutrient levels in water can lead to problems with algae blooms (Groundwork Sheffield, 2011).

3.4.3.7 Economics

Initial capital costs are higher compared to traditional roofing materials, but the higher capital costs are often offset by the lower maintenance, replacement and utility costs (Chicago, 2014). Typically the costs per m^2 for applications in the automotive industry will be toward the lower end of these estimates due to economies of scale across large production sites (Priddle, 2013). However, for retrofitting green roofs on existing sites, the increased weight of the roof may lead to higher overall costs for the building (Schleicher – personal comm., 2014).

Table 3-22: Typical installation and maintenance costs for green roofs

	€/m^2
Installation	60 to 115
Maintenance	0.4 to 4

Notes: Assumed conversion factor of $ to € of 0.72.

Source: (Priddle, 2013).

Where green roofs are used on a new development, it is sometimes possible for cost savings made on the drainage package to be used to offset the additional cost of the green roof installation (Groundwork Sheffield, 2011). Retrofitted systems can be costly if the additional weight requires extra roof support.

3.4.3.8 Driving force for implementation

Many green roofs are built to collect and filter rainfall in order to comply with regulations and government fees with respect to stormwater runoff management.

3.4.3.9 Reference organisations

Ford Motor Company's River Rouge Plant (USA) has a sedum planted roof based on a thin, four-layer, mat-like system instead of loose soil, in order to reduce the weight (Priddle, 2013).

A new-build extensive system installed at Rolls-Royce (BMW) Goodwood Plant (UK) covers an area of 32,000 m^2 to help it blend in with its countryside surroundings (AutoX, 2012).

3.4.3.10 Reference literature

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3.4.4 Alternative energy sources – renewable energy generation

SUMMARY OVERVIEW:				
Renewable energy generation can entirely meet the energy needs of an automotive manufacturing facility, although the achievability, cost and technologies required will vary significantly depending on the local renewable resource.				
Relevant lifecycle stages				
Management	Design	Supply chain	**Manufacturing**	End-of-life
Main environmental benefits				
Energy consumption	Resource use and waste	Water use & consumption	**Emissions to air, water, soil**	Ecosystems & biodiversity
Environmental indicators				
• Percentage of production sites assessed for potential and opportunities for use of renewable energy sources • Percentage of site energy needs met by renewable sources • Percentage reduction in energy consumption from fossil fuels • Reduction in energy consumption from fossil fuels (MWh or TJ)				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Implementing detailed energy monitoring and management systems; • Increasing the efficiency of energy-using processes			
Related BEMPS	N/A			

3.4.4.1 Description

This section describes on-site renewable energy generation – that is, generation facilities that are linked to a particular site. Renewable energy is defined as: "*energy generated by fuel sources that restore themselves over a short period of time and do not diminish"* such as sunlight, wind, rain, biomass and geothermal heat (EPA, 2014).

The first priority must always be to reduce energy consumption as far as possible before considering fuel switching to a renewable source – see relevant guidance in *Section 3.5: Key manufacturing processes.* Once options for energy efficiency have been fully explored, renewable energy should be considered to reduce the emissions of the remaining demand. An alternative approach would be to purchase renewable energy from external suppliers, such as through "green" electricity tariffs. This is not considered in detail; however it should be noted that in some cases it may be a more cost-effective option, particularly in locations with low renewable energy generation potential.

Energy is consumed throughout all processes involved in manufacturing cars. In 2012, almost 40 million MWh of energy was consumed by the European car manufacturing industry (equivalent to over 11 million tCO_2) (ACEA, 2013). The suitability of different renewable energy projects depends on the nature of the demand, local natural resources and the existing supply network. Table 3-23 shows a summary of possible renewable energy sources that could be suitable for many car manufacturing sites.

Table 3-23 – Renewable energy examples

Energy Source	Brief description
Solar thermal: Flat plate	Flat plate or evacuated tube solar collectors can be placed on building roofs or in adjacent areas to heat direct hot water.
Solar thermal: CSP	Concentrating solar power (CSP) technology uses mirrors to reflect the sun's rays onto a heat transfer fluid that can be used to supply heat for end-use applications or to generate electricity through conventional steam turbines. There are four main types (trough, Fresnel, tower and dish). The trough is the most mature technology, while solar dishes may also be suitable for distributed generation.
Solar photovoltaic	Photovoltaics (PV) convert sunlight into electricity. Generated electricity may be used for onsite processes or fed into the grid in order to avail of feed-in tariffs for solar electricity.
Wind turbines	Building-mounted wind turbines with a capacity of 1-6 kW are an emerging technology with low electricity outputs and currently offer a poor return on investment compared with alternative renewable energy options. Therefore, best practice is to install on-site free standing turbines of tens to hundreds of kW capacity where space and wind conditions allow, or to invest in large offsite wind turbines.
Biomass heating	Biomass energy (or bioenergy) utilises energy stored in plants, as well as plant material and organic material from animals. The main source is usually wood or pellet boilers that may be used to heat water for industrial processes.
Landfill gas	When waste is deposited into landfills anaerobic decomposition occurs. During this decomposition stage, landfill gas is produced, which is made up largely of methane.
Geothermal heat	Geothermal energy is generated from within the Earth. This heat can be contained as either steam or hot water and can then be used to generate electricity or heat buildings.
Hydroelectric generation	Various types of hydroelectric schemes are currently being utilised: 1. Storage schemes involve impounding water in a reservoir that feeds a turbine and generator that are usually located within the dam itself; 2. Run-of-river (micro-hydro) schemes use the natural flow of a river. Both storage and run-of-river schemes can be diversion schemes, where water is channelled from a source to a remote powerhouse containing the turbine and generator.

Source: Adapted from (European Commission, 2012), (IRENA, 2013), (DECC, 2013)

3.4.4.2 Achieved environmental benefits

Renewable energy sources have significant potential to reduce greenhouse gas emissions, as well as reducing primary energy consumption from finite fossil fuel resources. The environmental benefits are highly variable from project to project.

Some examples of how the renewable energy sources have been utilised by the car manufacturing industry, and the associated benefits achieved, are listed below:

- At BMW's Leipzig plant (Germany) all of the energy required to produce their i3 model is supplied by renewable energy. Four Nordex N100/2500 **wind turbines** produce 26 GWh a year, which exceeds the facility's requirements to produce the i3 – the excess is redirected to other processes at the Leipzig site (meeting around a fifth of the overall power requirement of the plant (BMW, 2013), (BMW Website, 2014);
- The energy required at Volkswagen's facility in Polkowice (Poland) is completely met by **hydroelectric power** instead of conventional power (Volkswagen, 2012);
- SEAT Martorell (Spain) has an 11 MW **solar PV** project. It consists of 53,000 solar panels installed across 276,000 m^2 of workshop and storage facility roofs, costing an estimated €35 million. The array is expected to generate 15 million kWh per year, equivalent to 25% of the

energy required for the annual production of the new SEAT Leon. The environmental savings achieved include the reduction of 7,000 tonnes of CO_2 per year (Business Green, 2013);

- In 2007, the Volvo Group presented the world's first CO_2 neutral automotive factory in Gent, Belgium. Investments were made in **wind power** to provide electricity. Around 50% of electricity here is produced by three 2 MW wind turbines. The windmills have a mast height of 100 m and the sails a radius of 40 m. All three are located inside the Volvo site (Volvo, 2012). In addition, a **biomass plant** has been installed for heating with a modern boiler that works on wood pellets and if necessary can switch to other environmentally friendly materials. In addition to this, on the roof of the boiler are 4,250 m^2 solar panels with an annual production of 500 MWh. As a result CO_2 emissions have declined by 14,000 tonnes annually (Volvo, 2012);
- As part of BMW's "**Gas to Energy**" project (initiated in 2001), four turbines were installed at its Spartanburg plant (USA) to pipe in methane gas from a nearby landfill site. The methane gas is used to turn the turbines which supply about 50% of the total electricity and hot water demands for the BMW site (and 100% of the energy used by the paint shop). In 2009, BMW replaced the original four turbines with two new highly efficient turbines. The new turbines increase the electrical output from 14% up to almost 30%. Implementation of the new landfill gas program reduces CO_2 emissions by 92,000 tonnes per year. Before this project was implemented, this gas was collected and burned in flares located at the landfill site in an effort to reduce odours and methane gas emissions (Climate Vision, n.d.) (AMS, 2007);
- At BMWs Research and Innovation Centre (FIZ) in Munich, a **ground water cooling system** was installed for environmentally friendly climate control, thereby saving 8,000 MWh of electricity and 5,000 tons of CO_2 each year (BMW Group, 2007).

At Toyota's TMMF plant in Valenciennes, a **biomass boiler** has replaced the gas heating used to heat baths. The wood pellets burnt in the boiler are sourced locally (northern France and Belgium), and provide an annual supply of 11,200 MWh, and reduce total CO_2 emissions from the plant by 6% (~1,200 tons/year) (Toyota - personal comm., 2014). In addition, a **solar wall** was installed on the south face of the plant, to preheat air by 5-10C as it enters the plant. The wall has a 400m^2 surface, and provides an output of 233 kWh/m^2. This provides 25% of the space heating required to heat the press shop and CO_2 savings of 25.21 tons/year (93 MWh/year). The payback period in this case is expected to be ~4-5 years (Toyota - personal comm., 2014).

3.4.4.3 Environmental indicators

Key indicators to monitor the implementation of this BEMP are:

- Percentage of production sites assessed for potential and opportunities for use of renewable energy sources;
- Percentage of site energy needs met by renewable sources;
- Percentage reduction in energy consumption from fossil fuels;
- Reduction in energy consumption from fossil fuels (MWh or TJ).

Most manufacturers measure energy consumption on a per vehicle or per engine basis (in MWh) and use this as benchmark.

Life cycle GHG emissions, expressed per kWh heat or electricity produced, is another environmental indicator of renewable energy performance that is useful for sustainability reporting (European Commission, 2012). Typical values are shown in Table 3-24.

Table 3-24: Overview of environmental indicators

Energy Source	Life cycle CO_2-eq/kWh
Solar thermal (flat plate)	0.046
Solar photovoltaic	0.154
Wind turbines	0.018
Biomass heating (wood chip)	0.028
Biomass heating (wood pellet)	0.056
Landfill gas	0.246
Geothermal heat	0.12

Energy Source	Life cycle CO_2-eq/kWh
Hydroelectric generation	0.01-0.03

Source: Adapted from (European Commission, 2012), (DECC/DEFRA, 2013), (Rybach, 2010), (EDF, 2014)

3.4.4.4 Cross-media effects

While often renewable energy is thought of as being "clean", in practice there are often cross-media effects. With careful implementation, these can be mitigated so that the overall environmental impacts will be positive. The main cross-media effects and options to mitigate them are summarised in Table 3-25.

Table 3-25: Overview of cross-media effects for different renewable options

Energy Source	Potential cross-media effects	Mitigation options
Solar thermal	The production of solar thermal collectors requires energy and materials, and emits gases such as CO_2. The energy embodied in solar thermal cells is typically paid back within two to three years of operation depending on site specific application, so that energy produced over the remaining ~20 year operating lifetime creates a large positive balance.	Maximise output through optimised siting and installation (e.g. south orientation), and ensuring a long operational lifetime.
Solar photovoltaic	Toxics in manufacturing and potential concerns with End-of-Life waste. As with solar collectors, the production of solar PV cells requires energy and materials and emits gases. Owing to lower conversion efficiencies and more complex production methods, payback times are estimated at three to four years against 30-year operating lifetimes. It is expected that payback times will be reduced to approximately one year with anticipated thin-film technology.	As above.
Wind turbines	Damage to wildlife (e.g. bird strike – although evidence on the severity of this impact suggests that it is relatively small). Embodied energy in wind turbines typically represents less than one year's electricity output over typical operating lifetimes of 20 years.	Maximise output through appropriate siting (e.g. in areas of high and consistent wind speeds).
Biomass heating	Air pollution (local). Wood burning emits CO, NOx, hydrocarbons, particles and soot to air and produces bottom ash for disposal. These substances indicate incomplete combustion performance, and occur especially during start-up, shut-down and load variation. Wood chip boilers typically emit slightly more polluting gases than pellet boilers owing to lower fuel homogeneity, but emissions are low compared with other solid fuel boilers. Indirect land use change (ILUC) impacts of biofuels may also be of concern – This relates to the consequence of releasing more carbon emissions due to land-use changes around the world induced by the expansion of croplands for ethanol or biodiesel production in response to the increased global demand for biofuels.	CO, hydrocarbons, soot and black carbon particles can be reduced by using continuously operating wood chip or wood pellet boilers.
Landfill gas	Methane leakage can occur during the landfill gas collection process. Rain, snow, and liquids created by the compaction and decomposition of solid waste, which can seep through a landfill cell ("leachate") is a potential pollutant of groundwater or surface waters.	Venting systems can be installed to prevent methane from diffusing underground, and to collect any gas released and burn it off. Drains can be installed to collect leachate that has percolated through the solid waste, which is then pumped to wastewater recovery points for treatment.

Energy Source	Potential cross-media effects	Mitigation options
Geothermal heat	Many systems use an antifreeze solution to keep the loop water from freezing in cold temperature conditions. These solutions have very low toxicity, but many produce CFCs and HCFCs, which add to environmental concerns.	Antifreeze solutions with low toxicity should be selected.
Hydroelectric generation	The reservoir of water for hydroelectric power releases large amounts of methane emissions. This is due to plant material in flooded areas decaying in an anaerobic environment, and forming methane. Hydroelectric power sites may also negatively affect the surrounding agriculture and wildlife. There may also be water quality issues due to changes in temperature and dissolved oxygen concentrations in the water released from the dam.	Oxygen concentrations in reservoirs may be increased by aerating reservoirs or installing advanced aerating turbine runners. Installation of "fish-friendly" turbine technologies can reduce downstream passage mortality.

Source: Adapted from (European Commission, 2012) (IPCC, 2007), (CSE, 2011), (KAB, 2013), (NHA, 2010)

3.4.4.5 Operational data

Detailed operational guidance is provided in the **Sectoral Reference Document for the Construction Sector** (European Commission, 2012).

In general, professional assistance should be sought to carry out feasibility studies for each site before installation of renewable energy generation, in order to determine the most environmentally beneficial and cost-effective sources. For example BMW reported that in 2010 around 80% of their production plants were assessed for their technical or physical potential for use of renewable energy sources (BMW, 2010).

This feasibility study will allow estimations to be made on factors such as:

- Estimated capital cost of the plant;
- Estimated operational and maintenance costs;
- Estimated payback period of the plant;
- Estimated internal rate of return.

Some EU countries are starting to see hybrid systems that link different renewable sources. For example, heating may be provided by a combination of solar thermal and biomass. Some are using district heat systems (often based on renewable sources) to balance electricity generation from variable sources, for example by using excess power generation on very windy days to heat water directly or with heat pumps (REN-21, 2013).

3.4.4.6 Applicability

The use of on-site renewable energy generation can be an attractive option to reduce carbon emissions from energy consumption. Currently, the uptake in on-site renewable generation varies widely between manufacturers and is influenced by various factors such as capital costs, potential cost savings or other financial returns, and the renewable energy potential of the specific site.

The potential to exploit particular renewable energy resources on-site depends on the location and site-specific factors such as climate, shading, available space, etc.

Table 3-26 – Applicability of different renewable technologies

Energy Source	Applications
Solar thermal	Flat plate and tube solar thermal can be applied to any building with suitable exposure to the sun. They can be placed on building roofs or in adjacent areas. CSP requires high direct solar irradiance to work and are therefore more interesting options for installation in very sunny regions (e.g. Southern Europe).
Solar photovoltaic	Solar photovoltaic cells can be installed on, or integrated into, the building envelope – in particular roofs, exterior walls and shading devices. Car and engine plants often have a large surface area of roofing (typically flat or 'serrated' types) that offer a good starting point for solar schemes.
Wind turbines	Applicable to buildings with suitable wind resource. There are no special environmental or landscape designations, however locations cannot be too close to airports, and may face opposition from local residents due to aesthetic reasons (AMS, 2007). Another potential issue is space. For example, Volvo's plant in Ghent was limited to constructing three wind turbines due to space constraints (AMS, 2007).
Biomass heating	Best suited to non-urban areas with a local wood supply and where combustion emissions pose a lower health risk. Transportation can be very expensive if the wood has to travel a long distance to get to its final destination, it is not an efficient option.
Landfill gas	Isolated or remote areas are best suited to avoid the potential variety of adverse impacts on these sites including nuisance odours.
Geothermal heat	Generally locations near to places with volcanic activity, places with geysers, hot water springs are potential geothermal sites. Areas subject to tectonic plate movements and frequent earthquakes are also potential areas. However, it is not necessary that these have to lead to a viable thermal reservoir. There could be blind geothermal resources as well with no indications at the top surface.
Hydroelectric generation	Requires a good topographical location along the path of a river. The perfect site is one where there is a wide and flat valley. The rock structure on which the dam will be constructed should be strong enough to sustain the weight of a dam and the water stored in it. The flow of water where the dam is constructed should be sufficient enough to fill the dam.

Source: Adapted from (European Commission, 2012), (IRENA, 2013), (British Columbia Ministry of Environment, 2010), (Bright Hub Engineering, 2010)

There can also be barriers in environmental permitting. Large–scale renewable energy technologies are subject to all the necessary environmental permits of major industrial facilities. Renewable energy generation using new technologies can face permitting hurdles until permitting officials are familiar with the environmental effects of the generation processes (EPA, 2014).

3.4.4.7 Economics

The costs of renewables are site specific, as many of these components can vary according to location. Costs are very variable, due to the diversity of resources on specific sites and the power output required. Most types of renewable energy also have some economies of scale, so larger installations have a lower per-kW installation cost. Table 3-27 provides indicative economic costs and the levelised cost of energy (LCOE), exclusive of subsidies or policy incentives (REN-21, 2013). The LCOE is the cost price of energy outputs (e.g., €/kWh) of a project that makes the present value of the revenues equal to the present value of the costs over the lifetime of the project. Subsidies may be available for the installation of many technologies, reducing net installation costs and payback periods. Although these are highly significant in determining the overall costs of a project, such schemes vary across countries and are subject to changes or certain conditions. Therefore, they are not explicitly included in the indication of costs below.

Table 3-27: Indicative costs comparisons for renewable energy sources

Technology	Type(s)	Plant size	Conversion efficiency	Capacity factor	Capital Costs (€/kW)	Typical energy costs (LCOE – €cents/kWh)
Solar thermal: Industrial process heat	Flat-plate, evacuated tube, parabolic trough, linear Fresnel	100 kWth–20 MWth	-	~100%	300 - 700	3 - 12
Solar thermal: Concentrating solar thermal power (CSP)	Parabolic trough, no storage	50–250 MW	-	20–40%	2,900 - 5,300	7 - 28
	Parabolic trough, with 6h storage			35–75%	5,200 – 7,200	12 - 27
Solar PV	Rooftop, fixed tilt	100-500 kW	10–30%	10–25%	1,100 - 1,900	12 - 28
	Ground-mounted utility-scale	2.5–250 MW (peak)			900 - 1,400	9 - 28
Wind	Onshore	1.5–3.5 MW	-	25–40%	1,300 - 1,300	4 - 12
Bioenergy combustion	Boiler/steam turbine Organic MSW	25-200 MW	25-35%	50-90%	600 - 3,300	4 - 15
	Co-fire				100 - 600	3 - 9
Bioenergy CHP	For heat and power	0.5–100 kWth	60–80%	70–80%	400 - 4,400	3 - 9
Bioenergy heat plant	Hot water / heating / cooling	0.1–15 MWth	80–90%	~50–90%	300 - 900	3 - 21
Biogas	Landfill gas	1–20 MW	25–40%	50–90%	1,400 - 1,600	3 - 5
Geothermal power	Condensing flash	1-100 MW	-	60-90%	1,500 - 3,100	4 - 9
	Binary				1,800 - 4,500	5 - 10
Hydropower	Off-grid/rural - run-of-river, hydrokinetic, diurnal storage	0.1–1,000 kW	-	30–60%	900 - 2,600	4 - 29

Notes: Conversion factor 0.73 USD to EUR. Several components determine the levelised costs of energy (LCOE), including: resource quality, equipment cost and performance, balance of system/project costs (including labour), operations and maintenance costs, fuel costs (biomass), the cost of capital, and productive lifetime of the project.

Source: (REN-21, 2013)

It is also important to note that the rapid growth in installed capacity of some renewable technologies and their associated cost reductions mean that data can become outdated quickly; solar PV costs, in particular, are changing rapidly (REN-21, 2013).

3.4.4.8 Driving force for implementation

The main driving forces for installation of renewable energy sources are (European Commission, 2012):

- Government financial assistance for renewable energy installation;
- Corporate social responsibility;
- Energy security.

3.4.4.9 Reference organisations

Many manufacturers have installed on-site renewable energy, although to varying degrees and using different technologies. Those referenced as examples are by no means exhaustive; however as an example, Volkswagen meets one-third of its energy needs from renewable generation across the group as a whole (Volkswagen, 2013) – the level achieved at individual sites varies depending on the

local renewable sources, and can reach up to 100% where hydroelectric power is available. Across BMW group, the share of renewable energy, as a percentage of total power consumed, reached 48% in 2013 (BMW, 2013).

3.4.4.10 Reference literature

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3.4.5 Optimisation of lighting in automotive manufacturing plants

SUMMARY OVERVIEW:				
Energy use for lighting is best achieved through a combination of using efficient lighting technologies (such as light-emitting diodes) as well as zonal management strategies.				
Relevant lifecycle stages				
Management	Design	Supply chain	**Manufacturing**	End-of-life
Main environmental benefits				
Energy consumption	Resource use and waste	Water use & consumption	Emissions to air, water, soil	Ecosystems & biodiversity
Environmental indicators				
• Implementation of energy-efficient lighting and zonal strategies (% of lighting areas within a site, % of total sites).				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Implementing detailed energy monitoring and management systems;			
Related BEMPS	• N/A			

3.4.5.1 Description

Lighting can account for a significant proportion of electricity consumption at a car manufacturing plant and its optimisation can be among the cheapest energy-saving measures available. Lighting is used either to provide ambient light throughout the facility or to provide task lighting to specific areas.

Some of the guidance in this section has been adapted from the **Sectoral Reference Document on Best Environmental Management Practices for the Construction Sector** (European Commission, 2012), where additional technical descriptions of the lighting options can be found. However, the guidance that follows has been tailored to make it more specific and relevant for the automotive sector, particularly considering the applications and operational data.

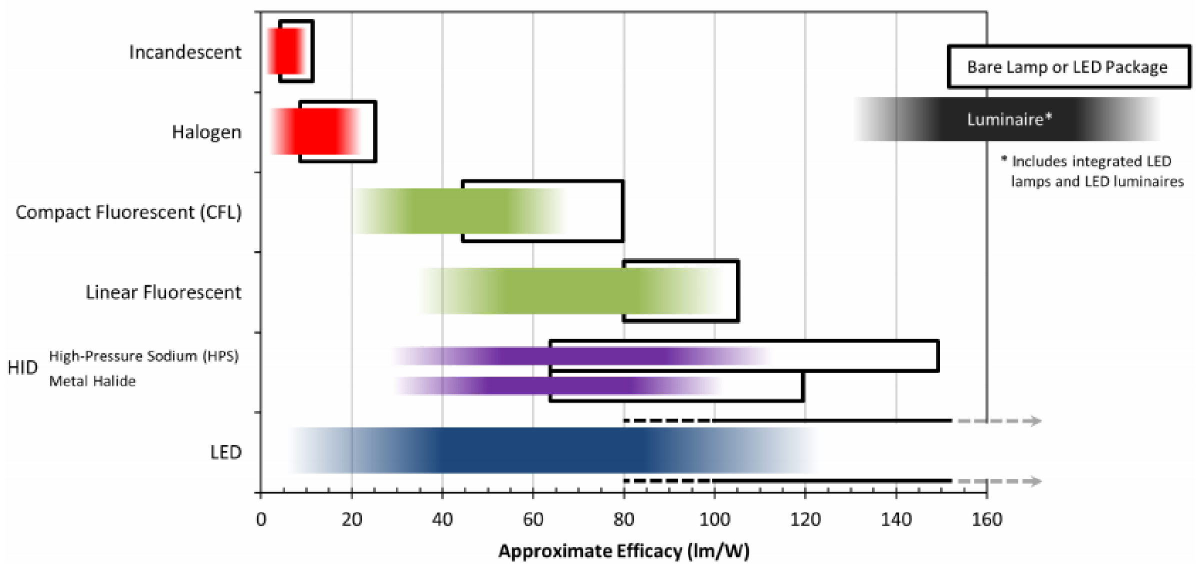
Several steps can be taken to optimise lighting energy efficiency:

- **Increasing the efficiency of lighting devices**. Lighting should achieve high levels of energy efficiency while still ensuring sufficient brightness for safe working. Efficient bulbs include halogen lamps, fluorescent lamps, light emitting diodes (LED) and gas discharge lamps (European Commission, 2012).
- **Management of lighting on a “zonal” basis**, so that lighting is switched on or off according to requirements in particular areas without affecting work elsewhere.

Combining the measures above can be the most effective and comprehensive way to reduce lighting energy.

Figure 3-14 shows the approximate range of efficacy for different light sources. There is a large range because all luminaire types are grouped together—but in general, the efficacy of current Light Emitting Diode (LED) products is similar to fluorescent and High Intensity Discharge (HID) products. However, the variability in LED products is greater than for the more mature technologies and the products are improving rapidly (US DoE, 2013). Of the light source technologies listed, only LED is expected to make substantial increases in efficacy in the near future.

Figure 3-14: Approximate range of efficacy for various common light sources



Notes: Efficacy refers to the emitted flux (lumens) divided by power draw (watts). The black boxes show the efficacy of bare conventional lamps or LED packages, which can vary based on construction, materials, wattage, or other factors. The shaded regions show luminaire efficacy, which considers the entire system, including driver, thermal, and optical losses.

Source: (US DoE, 2013)

For the non-domestic sector, linear fluorescent tubes are the most common efficient lamps mainly used for commercial lighting in offices, commercial buildings and low-bay industrial applications (below 5 meters) (AEA Technology, 2012). T5 lamps are the most efficient of all fluorescent tubes, with efficacy values from 38 to 106 lm/W, good colour rendering and colour appearance, and a lifetime of up to 48,000 hours (AEA Technology, 2012).

3.4.5.2 Achieved environmental benefits

The main environmental benefit is a reduction in electricity consumption – for example, one manufacturer claims that **LED lighting** can reduce operational lighting energy consumption by up to 60% compared to traditional lighting (Philips, 2014). Other systems may also improve efficiency - for example the T5 system of **linear fluorescent lamps** from Schneider Electric is used at Volkswagen Chattanooga, where it reportedly achieves an appropriate illumination level with an energy expenditure of less than 4 W per square metre of floorspace (around 20% savings compared to conventional lighting systems) (Farish, 2012). At Hyundai's Korean plants, metal lamps (430 watt hours) have now been replaced **by electrode-less lamps** (150Wh) and **high efficiency fluorescent lighting** (54 Wh bulbs), cutting annual CO_2 emissions by a stated 6,000 tonnes (Brooks, 2010).

For external lighting, **LED lighting used in external locations** also minimises light pollution (Farish, 2012). At Audi Ingolstadt, introduction of LED lighting in multi-storey parking areas achieved savings of 97.5 kWh per parking space per year, with the additional benefit of being less harmful to wildlife by lowering the attraction for insects (Audi, 2013).

In terms of **management of lighting on a "zonal" basis**, electricity savings at Volvo's Torslanda plant (Sweden) from turning off lights during non-working hours were estimated at 630 kW (56%) in the final assembly plant, 370 kW (30%) in the paint shops and 210 kW (18%) in the press shop (Galitsky & Worrell, 2008). An intelligent lighting system controlled by daylight and motion sensors installed at Hyundai Nošovice (Czech Republic) reduced power consumption by 30% (Helvar, 2013). For example, at lunch hour the corridors are lit more brightly and the workstations are dimmed.

3.4.5.3 Environmental indicators

At the organisational level, the implementation of energy-efficient lighting and zonal strategies should be measured (% of lighting areas within a site, % of total sites). For a single site, efficient lighting can be installed throughout the entire facility (Volkswagen, 2012).

At the luminaire level, products can be compared in terms of efficacy (lm/W). In use, energy consumption for lighting is typically measured per m^2 or per year.

Other important technical parameters include (AEA Technology, 2012):

- Luminance efficacy – Measured in lm/W, it describes the efficiency at which a lamp converts electricity into light. Usually, the higher the value the more efficient the lamp;
- Colour performance – Described by the colour rendering index (Ra), it is the ability of the lamp to show colours accurately. Best performing lamps have values between 80 and 100;
- Colour appearance – Described by the correlated colour temperature and measured in Kelvin (K), it characterises colour warmth and coolness. The warmer the light, the greater the Kelvin value. For example a GLS lamp will have a warm colour temperature of 2,700-3,000 K, to be compared with a cool colour temperature of 4,000-6,000 K for a lamp which mixes reasonably well with daylight, such as a cool white fluorescent tube;
- Lamp life – For most lamps this is the time when half of the lamps in a sample fail and is measured in hours.

3.4.5.4 Cross-media effects

Generally, since most impacts occur during the use phase the environmental impacts over the luminaire lifecycle are proportional to the efficiency in use. Fluorescent lamps contain small amounts of mercury, which complicates their disposal, as appropriate recycling methods have to be used (European Commission, 2012).

3.4.5.5 Operational data

Importantly, efficacy should not be the only factor when comparing products. Other performance characteristics, such as colour quality, luminous intensity distribution, and dimmability must be included in the decision (US DoE, 2013). These factors interlink to affect the overall performance and energy efficiency of the system. Detailed operational guidance is provided in the **Sectoral Reference Document for the Construction Sector** (European Commission, 2012).

Guidance on best practices for motor vehicle plant lighting is provided under the US EPA ENERGY STAR programme. A spreadsheet listing best practice lighting levels from companies participating in EPA's ENERGY STAR Motor Vehicles is available for download[17].

This provides a summary of the best practice lighting levels used by companies participating in the programme. The full guidance is very extensive and therefore not duplicated here in whole – as a general overview, Table 3-28 presents lighting levels in lux[18] for different manufacturing areas. The manufacturing areas covered include: assembly, body welding, paint, press, plastics, powertrain, casting, utilities, administrative and other areas.

Table 3-28: Guidance on best practice lighting levels in motor vehicle plants

Process area	Min (Lux)	Max (Lux)
General occupied building areas	100	300
General unoccupied building areas	10	50
Assembly	150	500
Body welding	300	1,000
Press	150	600
Plastics	150	1,500
Powertrain	100	1,000
Casting	150	1,500
Utilities	150	500
Administrative	100	500
Parking lots	12.5	30

[17] http://www.energystar.gov/buildings/tools-and-resources/motor-vehicle-plant-lighting-level-best-practices
[18] Illuminance, measured in lux or lumens per m^2, is a measure of intensity of light (as perceived by the human eye) that passes through a surface.

Source: (EPA, 2010)

3.4.5.6 Applicability

Most fluorescent lamps do not provide full brightness immediately after being turned on. This is particularly relevant to amalgam compact fluorescent lamps (CFLs), which can take three minutes or more to reach full light output. HID lamps have even longer warm up times, ranging from several minutes for metal halide to ten minutes or more for high-pressure sodium (HPS). Therefore LEDs have an advantage when used in conjunction with occupancy sensors or day-light sensors that rely on on-off operation as they reach full brightness almost immediately (US DoE, 2012). For external work areas, the use of the LED technology may not provide sufficient brightness for safe working, although it can be used in less critical areas such as parking lots.

3.4.5.7 Economics

In general investment in efficient artificial light sources is more than compensated by the lifetime savings. Current estimates for the cost and performance of different lighting types are shown in Table 3-29.

Table 3-29: Typical current international values and ranges for commercial lighting applications

Technology Variants	Metal halide	High pressure sodium (SON)	Fluorescent tubes Triphosphor coated	LED
Typical applications	Commercial uses with good colour rendering: high bay areas (indoor space with high ceiling), floodlighting, external lighting, retail, hotels	High bay areas, flood lighting, street lighting, etc., that need to be lit for a long periods	Offices, commercial buildings, and low bay industrial uses (below 5 m)	A variety of different applications
Typical size (W)	70-400 (up to 1,000 available)	30-400	T8[19]: 10–70 T5: 6–80	1-16
Energy efficiency or 'efficacy' (Lm/W)	70-107	65-103	T8: 60-100 T5: 38-106	>25-100
Lifetime (hours x 1,000)	6-20	12–28.5	T8: 12–60 T5: 16–48	12- >50
Colour Temperature (K)	3,000-6,000	2,000	2,700–6,500	2,800-6,500
Colour Rendering Index (CRI)	65-96	25	80 – 85	80
Product cost (€/unit)	11 - 50 (special types over 100)	8 - 25	T8: 2 – 19 T5: 3 –10	11 - 57

Source: (AEA Technology, 2012).

The rated lifetime can be especially important where access is difficult or where maintenance costs are high, and in many cases the maintenance savings (as opposed to energy savings) are the primary factor determining the payback period for a lighting product (US DoE, 2012).

3.4.5.8 Driving force for implementation

One of the main driving forces is the potential for cost reduction. In Europe, Regulation (EC) 244/2009 came into force which sets ecodesign requirements for CFLs and GLS lamps and aims to remove the

[19] The two most commonly used types of fluorescent tubes have two common diameters: 26mm (T8) and 16mm (T5).

most energy inefficient non-directional lamps from the market in favour of more energy efficient alternatives (AEA Technology, 2012).

3.4.5.9 Reference organisations

Organisations mentioned in this BEMP include:

- Hyundai Nošovice (Czech Republic);
- Volkswagen Chattanooga (USA);
- Volvo Torslanda (Sweden).

3.4.5.10 Reference literature

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3.4.6 Biodiversity management

SUMMARY OVERVIEW:				
The focus of this section is on direct impacts, where companies can directly affect biodiversity on their premises, although it is noted that significant impacts occur in the supply chain.				
Relevant lifecycle stages				
Management	Design	Supply chain	**Manufacturing**	End-of-life
Main environmental benefits				
Energy consumption	Resource use and waste	Water use & consumption	Emissions to air, water, soil	**Ecosystems & biodiversity**
Environmental indicators				
• Inventory of land or other areas, owned, leased or managed by the company in or adjacent to protected areas or areas of high biodiversity value (area, m^2). • Plan for biodiversity friendly gardening in place for premises or other areas, owned, leased or managed by the company (yes/no). • If located in or adjacent to protected areas: Size of areas under biodiversity friendly management in comparison to total area of company sites (%). • Total size of restored habitats and/or areas to compensate for damages to biodiversity caused by the company (m2) in comparison to land used by the company (m^2).				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Ecosystem management reviews and strategy			
Related BEMPS	• Integrating environmental criteria into supply chain management • Green roofs			

3.4.6.1 Description

Comprehensive approaches for biodiversity management are far common in the automotive sector, where the current focus is typically on more established topics such as climate change, resource scarcity, energy efficiency and water (Global Nature Fund, 2013). However, these aspects also play an important role in biodiversity. Biodiversity relates to the variability among living organisms from all sources, and diversity within and between species and diversity of ecosystems. Biodiversity is not an “ecosystem service”, but rather it underpins the supply of all ecosystem services – that is, biodiversity conservation tends to support a broader range of ecosystem services and to enhance their productivity and resilience.

There is extensive literature documenting good and best practice measures with respect to biodiversity protection at the general level. The guidance in this section has been tailored to make it more relevant, and the guidance in this section is based on evidence from actions that are specific to the automotive sector. Site-specific aspects should include:

- **Measurement:** Measuring biodiversity first requires an understanding of how an organisation creates positive and negative impacts on biodiversity. A foundation of accurate information about land take, environmental impacts and protectable species is required for individual manufacturing locations before actions can be planned and taken. Best practice organisations have introduced extensive measurement activities at all of their sites using location-based biodiversity or risk screenings, including assessment of the surrounding areas, and measurement according to indicators and species inventories (Global Nature Fund, 2013).
- **Management and collaboration with stakeholders:** Managing the site to promote and maintain biodiversity, and conducting ecological compensation measures to minimise impacts. In addition, working in partnership with specialist organisations involved in biodiversity and educating staff and contractors in the importance of protecting and enhancing biodiversity;

- **Reporting:** sharing information with stakeholders about an organisation's activities, impacts, and performance in relation to biodiversity.

This section focusses on local, site-specific measures to protect biodiversity and ecosystems at the site level. The focus of this section is therefore on direct impacts, i.e. where companies can directly affect biodiversity on their premises. Direct effects can occur through soil and water contamination, pollution from manufacturing or landscape changes.

Indirect impacts occur in the supply chains or during the in-use phase, and should be considered as part of strategies at a higher level (defined in Section 3.2*: Cross-cutting operational best environmental management practices*). Since many important biodiversity impacts occur in the supply chains, considering this aspect during procurement is an important measure although few automotive manufacturers currently include any specific biodiversity requirements (Global Nature Fund, 2013).

In particular, the impact of transport on biodiversity can be important, especially related to shipping. The introduction of non-native species is one of the five drivers for biodiversity loss and considered to be a serious risk for society (Hörmann, personal comm., 2014). Ballast water discharged from ships is one of the pathways for the introduction and spread of aquatic nuisance/invasive species ranging from pants, animals, bacteria, and pathogens. They may displace native species, degrade native habitats and disrupt human social and economic activities that depend on water resources. Companies should request from their carriers a Ballast Water and Sediments Management Plan in Shipments which avoids an introduction on invasive species (Hörmann, personal comm., 2014).

3.4.6.2 Achieved environmental benefits

Achieved environmental benefits must be considered in terms of their ability to reduce direct impacts on biodiversity, thereby increasing the conservation of natural resources, and associated biodiversity and ecosystem service provision.

Daimler list the following benefits to the environment following from comprehensive and systematic documentation and environmental assessment of land around a production site (Daimler, 2011)

- Hazardous waste sites and natural habitats are accurately documented.
- Degraded areas are systematically restored and upgraded in order to improve the food supply for native species.
- Biodiversity is promoted in areas suitable for use as habitats (e.g. temporary hives for non-domesticated bees, dry stone walls etc.) as well as by nesting and colonization aids (peregrine falcon nest boxes, noise attractors for common swifts, bat boxes etc.).
- The sustainable nature of the measures is ensured by monitoring systems.

3.4.6.3 Environmental indicators

The following set of basic key indicators are applicable for all companies. They are based on suggestions from the European Business Biodiversity Campaign, which aimed to establish indicators compatible with the requirements of EMAS and ISO14001 so that biodiversity can be more easily incorporated into existing management systems (Business Biodiversity, 2013):

- General indicators:
  - Number of projects / collaborations with stakeholders to address biodiversity issues.
  - Procedure /instruments in place to analyse biodiversity related feedback from customers, stakeholder, suppliers (quality indicator).
  - Feedback from stakeholders on the overall biodiversity performance of a company (quality indicator).
- Site-specific indicators:
  - Inventory of land or other areas, owned, leased or managed by the company in or adjacent to protected areas or areas of high biodiversity value (area, m^2).
  - Plan for biodiversity friendly gardening in place for premises or other areas, owned, leased or managed by the company (yes/no).
  - If located in or adjacent to protected areas: Size of areas under biodiversity friendly management in comparison to total area of company sites (%).

- Total size of restored habitats and/or areas to compensate for damages to biodiversity caused by the company (m^2) in comparison to land used by the company (m^2).

Relevant indicators for biodiversity are an active area of research and hence organisations should check for the latest available guidance. The core set of indicators for biodiversity developed by Business Biodiversity are rather extensive and are available online: http://www.business-biodiversity.eu/default.asp?Menue=233

3.4.6.4 *Cross-media effects*

Measures to protect biodiversity in this context are rarely associated with significant cross-media effects. However, zoning to protect high nature value areas may lead to more concentrated development that can have additional environmental benefits in relation to efficient service provision, but that may give rise to localised pressures (noise, air quality, etc.) (European Commission, 2013).

3.4.6.5 *Operational data*

Measurement – operational data

The key focus is on direct drivers of biodiversity change. There are various drivers, but the ones most relevant for the automotive industry include (GRI, 2007) (Global Nature Fund, 2013):

- ;
- **Conversion or destruction of habitats. ,** e.g. land conversion resulting from site development
- **Pollution:** Soil and water are particularly at risk due to the pollutants used in production. Leakages of nitrogen-or sulphur-containing pollutants can cause acidification, whilst hazardous substances (including heavy metal compounds) can be detrimental to wildlife.
- **Invasive species.** Organisations can unintentionally introduce species (e.g., insects that have nested in cargo containers or aquatic organisms in shipping ballast) into habitats;
- **Overexploitation of resources**: that are available in finite quantities with different renewal cycle;
- **Climate change,** e.g. human activities contributing to global warming such as deforestation and use of fossil fuels;

Initial screening of the biodiversity linkages and performance of a company can be achieved by can be achieved by following existing guidelines. For example, **biodiversity checks** are offered as part of European Business and Biodiversity Campaign[20]. They provides a first overview on biodiversity opportunities, impacts and risks to a company according to the procedure of environmental management systems EMAS III and ISO 14001 and based on the philosophy and objectives of the Convention on Biological Diversity (CBD)[21]. A few automotive manufacturers have opted to conduct biodiversity checks at their sites under this scheme. The Biodiversity Check examines the company's direct and indirect impacts on biodiversity in the areas of strategy, management, public relations, company premises, procurement, product development and production, logistics and transport, sales and marketing etc. (see the case study in Operational Data).

It is also increasingly common for manufacturers to cooperate with environmental specialists to establish their own ecological indicators for monitoring and evaluation, as well as species inventories and lists of priorities for further action (e.g. Fiat, BMW and Daimler) (Global Nature Fund, 2013).

Further examples of biodiversity measurement carried out at automotive production plants are shown in Table 3-30.

[20] http://www.business-biodiversity.eu/
[21] An international effort led by the United National Environment Programme: http://www.cbd.int/

Table 3-30: Examples of biodiversity measures at automotive production plants

Example measure	Case study implementation	Results	Reference
Measurement using the Biodiversity Check	To analyse biodiversity-related effects of production at the Sindelfingen plant, Daimler has performed the Biodiversity Check of the European Business and Biodiversity Campaign.	Daimler has established that ~16 hectares of viable green spaces at the location Sindelfingen could be protected through corresponding improvement.	**Daimler** **Germany** (Global Nature Fund, 2013); (Stöbener, 2012).
Measurement based on risk analysis	Since 2010, Volkswagen has teamed up with external partners in the scientific and insurance sectors to prepare risk analyses that identify the emission risks arising from the company's operations, such as exhaust air, wastewater, waste, noise or vibration. Volkswagen then sets them against the potential adverse effects on water, soil and biodiversity in the local environment and evaluates them.	This analysis has resulted in much better information about the ecological integration of the factories in their individual landscape settings, and also made improvements in efficiency and savings in costs.	**Volkswagen** **Germany** (Biodiversity in Good Company, 2011)
Collaboration with research institutions to develop measurement indicators	Fiat worked in collaboration with the Department for Animal and Human Biology at the University of Turin, to develop a FIAT Group Biodiversity Value Index and corresponding guidelines for its application. The index measures the biodiversity at and surrounding corporate locations based on recognized ecological indices and existing problems at the respective sites.	Two application studies have already been carried out, with an expansion planned for sites in or near areas with high biodiversity.	**Fiat** **Italy** (Global Nature Fund, 2013)

Management and collaboration with stakeholders

Many automotive companies carry out voluntary conservation measures, albeit to a varying extent. The range includes relatively simple actions such as environmental education and conservation projects (e.g. tree planting).

However, some frontrunner organisations have systems in place to ensure systemic collaboration with local stakeholders and NGOs in the areas of biodiversity and nature conservation. Further examples of biodiversity measurement carried out at automotive production plants are shown in Table 3-31.

Table 3-31: Examples of management and collaboration with stakeholders

Example measure	Case study implementation	Results	Reference
Minimising land use	Daimler's production facilities cover a total area of about 4,000 hectares (10,000 acres), around 55% of which is covered by buildings, roads, and parking areas. Daimler use these surfaces as efficiently as possible – for example through multi-story buildings and high-density construction.	In cooperation with nature conservation organisations and public agencies, they are transforming open areas at the plants into species-rich meadows instead of lawns. Industrial architecture can also provide a habitat for threatened animal species. At Daimler's plant in Wörth, peregrine falcons nest on top of a chimney.	**Daimler** **Germany** (Daimler, 2011)
Attracting wildlife	At the Gaggenau plant, Daimler set up nest boxes and a noise attractor to encourage common swifts to colonize the area, built dry stone walls and created areas of nutrient-poor grassland, the facility is planning to attract certain plant species and set up various nesting and breeding aids, especially for assisting plant and animal species from Baden-Württemberg's list of 111 species that are particularly in need of help.	These measures are expected to facilitate a permanent improvement to local biodiversity with little effort.	**Daimler** **Germany** (Daimler, 2011)
Collaboration with conservation organisations	To date, GM has initiated habitat management programmes to increase the biodiversity at 21 locations worldwide. GM collaborates closely with the Wildlife Habitat Council, an association of nearly 100 large, generally global corporations and NGOs.	The habitat management programs will be certified by the Wildlife Habitat Council. GM are aiming to certify all of their properties worldwide by 2020.	**GM** **Global** (Global Nature Fund, 2013)
Collaboration with suppliers	Volkswagen is a founding member of the German Biodiversity Initiative "Biodiversity in Good Company" (BIGC) and has committed to establishing corporate biodiversity management as well as to comply with and support the CBD objectives by signing the BIGC Leadership Declaration.	As part of its BIGC membership, Volkswagen has committed to inform its suppliers through the proprietary B2B platform of biodiversity objectives and to encourage the protection of biodiversity.	**Volkswagen** **Germany** (Global Nature Fund, 2013)

Reporting – operational data

Reporting is critical to making the most of the reputational benefits of implementing biodiversity measures, as well as sharing information to encourage environmental protection. For example, Volkswagen has committed to the preparation of ecological reports for its German sites, as well as meeting the requirements of the Global Reporting Initiative (GRI) (Volkswagen, 2012).

In order to ensure reporting is effective, automotive manufacturers should (GRI, 2007)**:**

- Incorporate stakeholders' values in combination with scientific assessments, to determine which ecosystem services are important in a given context, and which biodiversity impacts are considered acceptable;
- Communicate its understanding of how its activities affect biodiversity;
- Outline its approach and performance in the context of its perceived roles and responsibilities;
- Report the specific policies and management approaches that are put in place to guide day-to-day activities;
- Use indicators (e.g. the GRI Environmental Performance Indicators) which specify the common information to be reported, as well as organisation-specific biodiversity indicators.

For further details on what to report, how to report and what indicators to use when reporting on biodiversity, please refer to **Biodiversity a GRI Reporting Resource** (GRI, 2007). The indicators and reporting framework are part of ongoing efforts in this area, and so organisations should check online for the latest guidance.

3.4.6.6 Applicability

Many of the approaches can be introduced at any time during site operation.

3.4.6.7 Economics

Since biodiversity is a public good, the economic importance of intact nature is often overlooked or underestimated (Global Nature Fund, 2013). Direct cost and benefit information is difficult to present, as it is highly dependent on specific business operations and approaches. Broadly, better management of ecosystems and biodiversity is expected to lead to better risk management, thereby increasing revenue, saving costs, boosting asset values and potentially share prices (WBCSD, 2011)

Biodiversity checks, such as the one referenced in the Operations section, allow organisations to take targeted measures in order to avoid or mitigate negative impacts on biodiversity and ecosystems and in some cases can reduce costs. For example, in cases where a business is required to enlarge its site area for production, they may be obliged to implement compensatory measures. If these measures are taken in advance the cost to the company can be reduced (Business Biodiversity, 2011). Furthermore, timely assessment of impacts to biodiversity can reduce operational risks (e.g. reputational risks or penalties for damage to ecosystems), and heighten employee motivation (Stöbener, 2012). Businesses that address environmental impacts at an early stage gain a competitive advantage, and put themselves in a position to anticipate legal requirements (Stöbener, 2012).

3.4.6.8 Driving force for implementation

Companies may anticipate that biodiversity (and ecosystem) issues will be more consistently incorporated into public policies, regulations, and political decisions. For example, in 2011 the European Union adopted the Biodiversity Strategy to 2020. The strategy aims to halt biodiversity loss in the EU, restore ecosystems where possible, and step up efforts to avert global biodiversity loss.

Opportunities for the automotive sector also include (Business Biodiversity, 2011):

- Reputational benefits;
- Earned credits (currently applicable to Germany) that can be used for components in later construction projects;
- Securement of corporate production basis, e.g. by protection of water resources.

3.4.6.9 Reference organisations

Car manufacturers mentioned in this chapter include Daimler, Volkswagen, Fiat, GM, Toyota and Ford.

3.4.6.10 Reference literature

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3.5 Key manufacturing processes

3.5.1 Section overview and technique portfolio

A distinctive feature of the automotive industry are the long and complex supply chains, and the high content of externally-produced components and subassemblies in the final vehicle. As a consequence, many of the best practices are common across general manufacturing operations for which specific and detailed guidance exists in other documents.

Therefore, the focus of this section is on key manufacturing processes that are highly specific to the automotive sector, as well as drawing attention to the wealth of existing guidance that should be considered at best practice manufacturing sites.

This section provides guidance on the following processes for which additional sector-specific guidance could be beneficial:

- **Increasing the efficiency of energy-using processes – general guidance:** This section outlines real world examples of efficiency improvements that have been achieved in automotive manufacturing facilities through implementing general best practices with respect to energy using processes;
- **Water-saving opportunities in automotive plants:** Significant opportunities may be available to avoid and/or reduce water consumption throughout automotive production processes;
- **Compendium of references for key manufacturing processes in the automotive sector:** The production of cars involves several functions that are common across different parts and sectors, including general material-handling, surface treatment and painting, casting and forming of metals etc. These are extensively covered by other existing guidance, and the reader is directed to these documents where relevant. Importantly, the reader is referred to other guidance in this section, where relevant links have been consolidated. Relevant processes include:
    - Foundry processes and fabrication of metal products;
    - Paint shop operations;
    - Electrical and electronic equipment;
    - Minimising releases of hazardous or polluting substances;
    - Manufacturing of other key components and materials, including metals, polymers, ceramics, textiles, glass, surface treatment and management of waste.

3.5.2 Increasing the efficiency of energy-using processes

SUMMARY OVERVIEW:				
Since the production demands of a manufacturing plant may change over time, it is essential to conduct regular reviews of energy-using processes and identify whether there are options for improved controls, management, repairs and/or equipment replacement. This ensures that high levels of energy efficiency are maintained.				
Relevant lifecycle stages				
Management	Design	Supply chain	**Manufacturing**	End-of-life
Main environmental benefits				
Energy consumption	Resource use and waste	Water use & consumption	Emissions to air, water, soil	Ecosystems & biodiversity
Environmental indicators				
• Implementation of regular reviews of systems, automation, repair, maintenance and upgrades (% of sites)				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Implementing detailed energy monitoring and management systems;			
Related BEMPS	• N/A			

3.5.2.1 Description

Energy efficiency measures can be categorised by their utility systems – i.e. electrical motors, compressed air systems, heat and steam distribution etc. This best practice focusses on the optimisation of energy using processes through improved controls, management and equipment.

Since the processes carried out and/or the models manufactured at a plant may change, equipment purchased in previous years may no longer be optimal for its current application. Therefore proper system reviews, repair, maintenance and upgrades are an essential part of ensuring continuous high performance.

General review criteria applicable to automotive plants include an assessment of the following aspects:

- Increasing levels of automation where possible to improve quality and productivity – for examples, see *Section 3.2.3: Implementing detailed energy monitoring and management systems*;
- Retrofitting plants with energy-saving power units, plant machinery, robotics, efficient air conditioning and lighting systems (Volkswagen Group, 2007), (Daimler, 2013), (Fiat - personal comm., 2014);
- Optimising production machine cycle times (Daimler, 2013);
- Recalibrating ventilation systems, specifying intermittent operation and energy-saving stand-by measures (Volkswagen Group, 2007);
- Avoidance of compressed air where possible and replacing with electrical tools (Volkswagen Group, 2007), (Daimler, 2013);
- Checking for leaks and losses of compressed air where it is used (Daimler, 2013);
- Implementing heat recovery equipment (e.g. on compressed air systems, smoke extraction systems), use of industrial waste heat (e.g. from roll-pressing machinery), and cold generation in absorption equipment (Volkswagen, 2012);
- Using low carbon energy to power vehicles and machines in the assembly plant – for example, Volkswagen has introduced forklifts, tractor vehicles and retrieval machines powered by hydrogen fuel cells in its Spartanburg plant (BMW, 2010).

- Installing servo press drives in press shops (AIDA & Honda, 2010); (Skoda, 2012).

Decisions on how to optimise processes may also be defined by decision support criteria. For example, at existing Volkswagen plants, ecological objectives are met either by replacing or upgrading machinery or by redesigning production processes (depending on the age of the production equipment). The experts in Wolfsburg collaborate closely with each individual factory and devise customised development plans for each site (Volkswagen, 2013).

Detailed guidance on general approaches for the optimisation of specific energy-using systems and equipment is provided in the **Reference Document on Best Available Techniques for Energy Efficiency**[22] (European Commission, 2009). As such, the focus of this section is to provide a selection of real-world examples of achieved improvements in car manufacturing plants with respect to energy using processes.

A forthcoming Sectoral Reference Document on **Best Environmental Management Practices for fabricated metal products** will cover the environmental aspects of many generic processes relevant to metallic components that are used in vehicle production.

3.5.2.2 Achieved environmental benefits

The energy efficiency improvement potential will vary depending on the starting point and the processes/components that are targeted. Examples and typical improvements achieved in the automotive industry are described below:

- **Electric motors** have a variety of uses in auto manufacturing plants. Modern, energy-efficient motors may reduce energy consumption by up to 40% over older models (Galitsky & Worrell, 2008). In combination with frequency converters, electrical drives can be operated on a need-driven basis, allowing up to 70% reduction in energy consumption for fans, pumps or compressors (Holt, 2012).
- **Avoiding the use of compressed air systems where possible.** Some manufacturers are aiming to avoid the use of compressed air as far as possible (Volkswagen Group, 2007) (BMW, 2013);
- **Optimising compressed air systems where they cannot be avoided.** Compressed air systems have various uses such as instrumentation, robotic equipment and manual tools. It is typical for many existing plants to have insufficient volume flow regulation, high idle consumption rates and a lack of waste heat recovery. Potential energy savings in these areas often remain unidentified due to the complexity of the systems, but existing systems may be optimised to: reduce leakage (savings of up to 20%); reduce unnecessary system pressure (reducing grid pressure by one bar will tend to reduce energy consumption by 10%) and; use variable speed drives (InnoCaT, 2013a). For example, the compressed air system at Toyota's Valenciennes plant is checked every weekend for leaks, using ultrasonic testing. As a result, the current leakage at the plant has been reduced to ~10% (Toyota - personal comm., 2014);
- **Cogeneration** can offer energy savings of 15-45% compared to the use of electricity and heat from conventional power sources (Brown, 2007);
- **Waste heat recovery.** Heat generated from processes may be used as an additional heat source for supplying production heat or space heating. For example, Volkswagen Salzgitter saves 7.3 GWh per year recovering air compressors' waste heat for space heating (Industrieanzeiger, 2012). VW's Cordoba plant saves 2,800 MWh of energy per year by using energy recovered during production processes to operate the air conditioning systems in offices. In VW's Martin plant in Slovakia, heat pumps enable exhaust heat from cooling water to be reused. This reduces energy consumption by 2,450 MWh per year (Volkswagen, 2014);
- **Increasing automation.** In Volkswagen's Foshan plant, around 70% of the processes in the body shop are automated - robots place every weld spot accurately to the millimetre and save around 70% on energy (Volkswagen press release, 2014). Further guidance is provided in *Section 3.2.3: Implementing detailed energy monitoring and management systems*;
- **Just-in-time production.** Toyota's Valenciennes plant have recently installed a 'just-in-time' paint oven, which has resulted in energy savings of €65,000 per year (Toyota - personal comm., 2014).

[22] http://eippcb.jrc.ec.europa.eu/reference/BREF/ENE_Adopted_02-2009.pdf

- **Timers** are used at Toyota's Valenciennes plant for space heating, lighting and air pressure optimisation. Simple solutions such as shutting down certain equipment on weekends have saved the plant €60,000 per year (a 25% reduction in energy consumption) (Toyota - personal comm., 2014).
- **Energy-efficient welding, handling and transfer robots:** Newer robots incorporate shutdown or standby functions depending on which states they are in. For example, Comau robots consume 33-58% less energy when waiting for an interlock and 80% energy in standby mode (Fiat - personal comm., 2014).
- **Servo presses:** The precise energy savings and other environmental benefits will vary depending on the application and the technology that is being replaced, but typically energy consumption is around a third lower compared to conventional mechanical presses (Nicklin - personal comm., 2014). Servo Press technology tested at Fiat's Serbia plant has improved stamping quality and led to a reduction in waste due to a reduction of non-compliant parts (about 15%) and a 100% reduction in cooling water consumption (Fiat - personal comm., 2014).

3.5.2.3 Environmental indicators

Energy consumption (kWh) per vehicle or per plant per year (MWh/y) are standard industry measurements for general plant efficiency. The actual figure is dependent on the functions handled at each plant. Within a single plant, a comparison over time may be difficult due to changes in utilisation or changes in the models produced. Thus, the need for detailed process-level monitoring is stressed – relevant indicators are outlined in *Section 3.2.3: Implementing detailed energy monitoring and management systems*.

3.5.2.4 Cross-media effects

In general, there do not appear to be significant cross-media effects in the optimisation of energy using systems.

3.5.2.5 Operational data

It should be emphasised that in order to gain the greatest benefits, it is important to have an accurate energy efficiency monitoring system - see *Section 3.2.3: Implementing detailed energy monitoring and management systems*.

Based on the monitoring data, existing automotive plant performance should be evaluated. Taking a systems approach to optimising these areas typically involves the following steps (Galitsky & Worrell, 2008):

- Identify and document the conditions and specifications of the energy-using processes to provide a current systems inventory;
- Determine the needs and the actual use to determine whether units are properly sized and meeting current requirements;
- Develop guidelines for proactive repair/replacement decisions;
- Develop and implement predictive and preventative maintenance programs.

Continuous maintenance is also an essential aspect of long-lasting and high environmental performance. This includes activities such as cleaning, repair, re-calibration, testing, and/or the replacement of components.

3.5.2.6 Applicability

There are a wide range of energy consuming systems and processes to which optimisation measures can be applied across the processes and systems. However, the precise measures will vary depending on the specific plant – more detailed guidance is provided in the **Reference Document on Best Available Techniques for Energy Efficiency** (European Commission, 2009).

Not all plants will be able to implement cogeneration; in plants with little thermal process or heat requirements, cogeneration will not be a cost-effective strategy.

3.5.2.7 Economics

In general, the economic case for investments in energy-saving equipment has strengthened in recent years due to increases in energy prices and greater volatility. Investments are often economical where the energy costs are a major part of the total costs of ownership.

As an example, the investment costs for new servo press lines are estimated to be 20-30% more expensive compared to conventional lines (Altan, 2012). The capital outlay for a large automotive body press line (5 presses) is estimated by one expert to be around £50 million (€60 million) (Nicklin - personal comm., 2014), which is similar to the €66 million investment made by Skoda in 2013, for the PXL system in its Mladá Boleslav plant (Skoda, 2012).

3.5.2.8 Driving force for implementation

The economics of energy saving measures tends to be a major driving force. In addition, voluntary programmes such as the US EPA ENERGY STAR programme are encouraging further efficiency improvements.

3.5.2.9 Reference organisations

The European Commission's (2009) energy efficiency reference document contains further information. In the US, under the EPA's ENERGY STAR programme, organisations that have taken part and succeeded in meeting the 10% goal of energy reduction are regularly updated on the ENERGY STAR website[23].

3.5.2.10 Reference literature

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Volkswagen press release. (2014). The model factory. Available at: http://www.volkswagenag.com/content/vwcorp/info_center/en/themes/2014/02/The_model_factory.html (accessed 23/06/2014).

Volkswagen (2014) Think Blue. Factory. Increase sustainability. (accessed 02/09/2014).

3.5.3 Water-saving opportunities in automotive plants

SUMMARY OVERVIEW:				
Production process (other than the paint shop) and sanitary uses can be a significant water-consuming aspect of an industrial site; therefore, they should not be overlooked as an important part of an overall water-saving strategy. Best practice is to minimise water use and consumption at all facilities, regularly review the implementation of water efficiency measures and ensure that the majority of practices and appliances are classified as highly efficient				
Relevant lifecycle stages				
Management	Design	Supply chain	**Manufacturing**	End-of-life
Main environmental benefits				
Energy consumption	Resource use and waste	**Water use & consumption**	Emissions to air, water, soil	Ecosystems & biodiversity
Environmental indicators				
• Existing sites retrofitted with water-saving devices and processes (% of operations) • New sites designed with water-saving devices and processes (% of new sites) • Amount of water that is internally recycled (%).				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Water use strategy and management			
Related BEMPS	• Water recycling and rainwater harvesting			

3.5.3.1 Description

In automotive production, water is needed for many processes such as cooling machines, in air conditioning systems and in the paint shop. Due to the importance of the painting processes in contributing to overall manufacturing water use, dedicated guidance has been developed to help organisations reduce water use in car painting. Guidance on **Best Available Techniques Reference Document (BREF) for Surface Treatment Using Organic Solvents**, which covers all environmental aspects related to the painting of car bodies and components. For the latest documents, please refer to the online repository[24].

Outside of the painting process, several other water saving options may exist throughout a plant. A thorough water use review should be conducted in order to identify these (see *Section 3.2.5: Water use strategy and management*). For example, at BMW group most of the water used in car production is already optimised, but they have identified that there is still a considerable opportunity for savings in waste water from sanitary use (i.e. for taps, toilets and showers), which accounts for almost half of total water use at their manufacturing sites (BMW, 2012)[25]. Specific examples of water opportunities in the automotive sector are outlined below.

3.5.3.2 Achieved environmental benefits

The main environmental benefit is water use reduction. For example, re-using condensed water from compressors at VW's Anchieta plant in Brazil reduces their water consumption by 270 m³ per year (Volkswagen, 2014). But co-benefits can also arise: for example with respect to reduced energy consumption since energy and water costs are very often linked, e.g. reducing hot water for cleaning

[24] http://eippcb.jrc.ec.europa.eu/reference/
[25] Other significant end-uses being mainly evaporative cooling towers and the paint shop. The share varies depending on the site and the processes involved.

saves heating costs as well. The use of rainwater harvesting can also contribute to a reduction in flooding.

Table 3-32 outlines water-saving options specifically available for the automotive industry – however, the achieved water savings are only indicative due to the high variation between plants depending on the specific processes and equipment used.

Table 3-32: Estimated water saving from avoiding and reducing water use in the automotive industry

Type	Option	Approximate total water saving
Avoid	Dry sweep all areas before hosing	🌢 - 🌢🌢
	Eliminate leaks	🌢 - 🌢🌢
	Use alternatives to liquid ring pumps, vacuum pumps that require seal (gland) water	🌢 - 🌢🌢
Reduce	Improve efficiency of operations	🌢 - 🌢🌢
	Install flow restrictors on tap water supply line	🌢 - 🌢🌢
	Use water efficient nozzles for spray rinsing/hosing	🌢 - 🌢🌢
	Use timer rinse controls	🌢🌢
	Install water efficient staff amenities	🌢
	Use ultrasonic cleaning processes	🌢 - 🌢🌢🌢
	Counter-flow rinsing (water flows in opposite direction to material)	🌢 - 🌢🌢🌢
	Inter-stage rinsing (uses overflow as an intermediate rinse stage immediately upstream)	🌢 - 🌢🌢

Notes: 🌢 *= <5% total water saving;* 🌢🌢 *= 5 – 10% total water saving;* 🌢🌢🌢 *- over 10% total water saving*

Source: (Ai group, 2009)

Recycling of water- and oil-based coolants is also possible to a large extent in autonomotive manufacturing.

3.5.3.3 Environmental indicators

Organisations should monitor the uptake of practices and appliances that are considered to be water-efficient across their sites and processes. Results indicators for overall water consumption are likely to be dominated by the painting processes, so monitoring at the process level is recommended (see *Section 3.2.5: Water use strategy and management*).

3.5.3.4 Cross-media effects

Cross-media effects can be considered positive, as waste water is reduced, along with energy requirements for treatment and pumping (European Commission, 2012). Specific cross-media effects that should be considered in the automotive industry include (Ai group, 2009):

- Replacing an evaporative ("wet") cooling system with an air cooled ("dry") system can sometimes increase the facility energy consumption;
- Reducing volumes of wastewater can increase the concentration of contaminants.

3.5.3.5 Operational data

See the **Sectoral Reference Document for Best Environmental Management Practices for the Construction Sector** for more detailed operational data on general building-related water saving devices (European Commission, 2012).

For aspects with significant staff involvement (such as sanitary fittings), instigating staff behaviour change programmes, or implementing simple low-cost devices can reduce water use by up to 30% (WRAP , 2014).

3.5.3.6 *Applicability*

Water-saving devices should not compromise performance if chosen and installed correctly.

3.5.3.7 *Economics*

Economic information for buildings in general are provided in the **Sectoral Reference Document for Best Environmental Management Practices for the Construction Sector** (European Commission, 2012).

Table 3-33 indicates the range of expected costs for various water-saving options specifically available for the automotive industry. The costs are only indicative due to the high variation between plants.

Table 3-33: Estimated costs associated with options to avoid and reduce water use in the automotive industry

Type	Option	Approximate option cost
Avoid	Dry sweep all areas before hosing	Low
	Eliminate leaks	Low
	Use alternatives to liquid ring pumps, vacuum pumps that require seal (gland) water	Low - Medium
Reduce	Improve efficiency of operations	0 – High
	Install flow restrictors on tap water supply line	Low
	Use water efficient nozzles for spray rinsing/hosing	Low - Medium
	Use timer rinse controls	Low - Medium
	Install water efficient staff amenities	Low - Medium
	Use ultrasonic cleaning processes	Medium
	Counter-flow rinsing (water flows in opposite direction to material)	Low - High
	Inter-stage rinsing (uses overflow as an intermediate rinse stage immediately upstream)	Low – Medium

Notes: Low cost = up to €10k; Medium cost = between €10k to €100k; High cost = over €100k

Source: (Ai group, 2009)

3.5.3.8 *Driving force for implementation*

In many cases, the most significant driver will be cost savings, but customer and stakeholder requirements are also important (Zero Waste Scotland, 2012).

3.5.3.9 *Reference organisations*

The extent of take-up in the automotive sector is not extensively reported, but several manufacturers have highlighted their activities in this area – for example:

- BMW and Volkswagen are gradually replacing sanitary fittings with more efficient versions (BMW Group, 2012), (Volkswagen, 2013);
- Ford have highlighted their use of new cooling tower technologies such as electrolytic water softening to increase cooling tower cycles of concentration, thus lowering water consumption (Ford, 2012);
- BMW are gradually replacing open cooling towers with closed ones and using groundwater for cooling (BMW, 2013).

3.5.3.10 Reference literature

Ai group. (2009). Water saving factsheet: Automotive industry. Available at: http://pdf.aigroup.asn.au/environment/7082_WPA_fact_sheet_AUTO.pdf (accessed 11/06/2014).

BMW. (2013). Sustainable value report. Available at: http://www.bmwgroup.com/com/en/responsibility/svr_2013/index.html (accessed 18/06/2014).

BMW Group. (2012). Adding Value: Sustainable Value Report. Available at: http://www.bmwgroup.com/e/0_0_www_bmwgroup_com/verantwortung/svr_2012/umweltschutz.html (accessed 15/04/2014).

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Zero Waste Scotland. (2012). Implementing a water minimisation programme: A guide for organisations in Scotland. Available at: http://www.zerowastescotland.org.uk/sites/files/wrap/ZWS_Implementing_a_water_minimisation_programme_a%20_complete_guide_for_organisations_in_Scotland.pdf (accessed 15/04/2014).

3.5.4 Compendium of references for key manufacturing processes in the automotive sector

3.5.4.1 Description

The most energy-intensive and polluting operations in automotive manufacturing should be carefully optimised. The general scope for this document (see *Section 2.2: General scope for this study*) already highlighted that many environmental impacts are concentrated in certain key car manufacturing activities, and due to their importance they are already covered under other specific guidance documents.

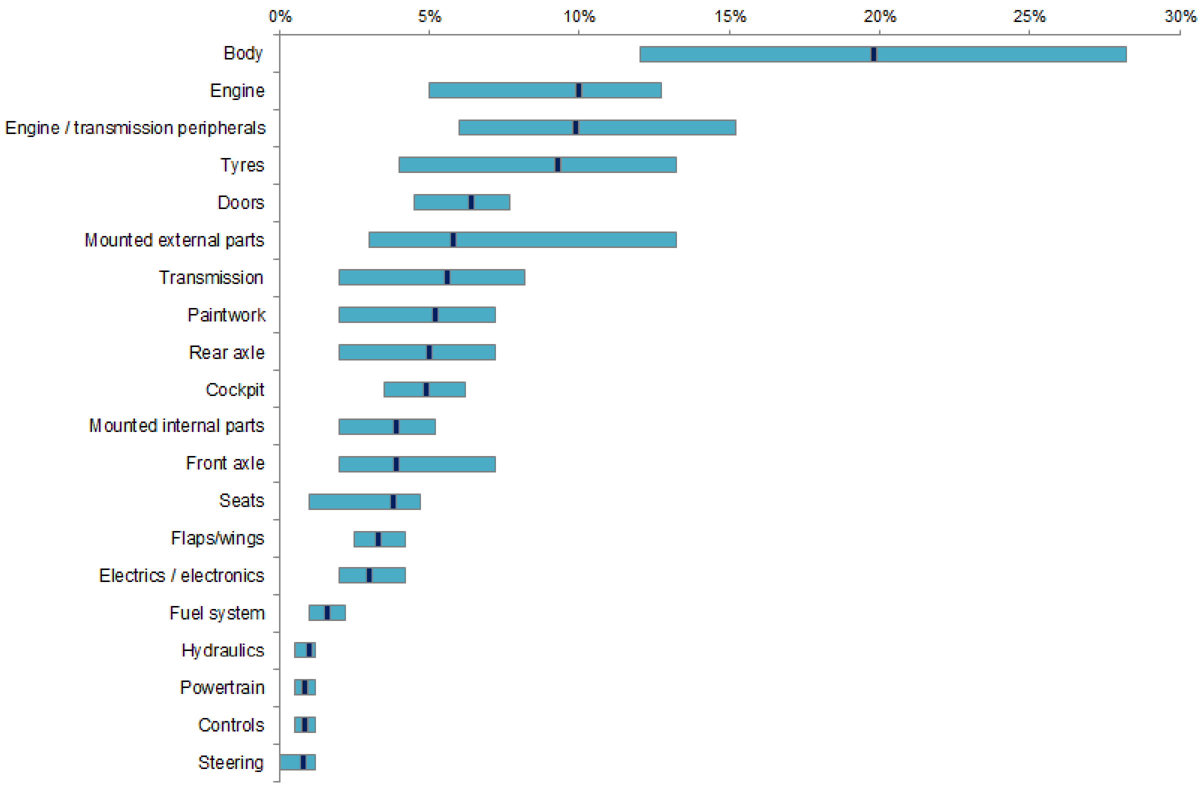
The sections below highlight the relevant areas that should be considered due to the importance of the environmental issues concerned, and direct the reader to the relevant guidance documents available. In the context of broader environmental performance and management, all of these processes should be included in cross-cutting monitoring and optimisation activities (see *Section 3.2: Cross-cutting operational best environmental management practices*).

3.5.4.2 Foundry processes and fabrication of metal products

These processes are highly significant in terms of energy consumption, waste production and water consumption.

Figure 3-15 shows the range of CO_2 emissions from production of various parts. In terms of the specific components involved, in general most large components made primarily of metal account for a significant share of CO_2 emissions (which are closely correlated with energy use) – including the vehicle body, engine and transmission (Mercedes, 2009). Other metallic components may also account for a significant proportion of energy consumption (e.g. exhaust, axles, transmission).

Figure 3-15: Range (light blue) and average (dark blue) share of production CO_2 emissions from different components



Source: Values taken from life cycle studies across five different Mercedes models (E-class, C-class, SL-class, M-class and GLK-class) (Mercedes, 2009).

A breakdown of water consumption due to different processes is shown in Table 3-34 Most of the water consumption occurs in producing iron and aluminium (Bras et al, 2012). The casting of metal

components has a high water consumption value because the high temperatures involved in treating the materials requires more water for cooling (Bras et al, 2012).

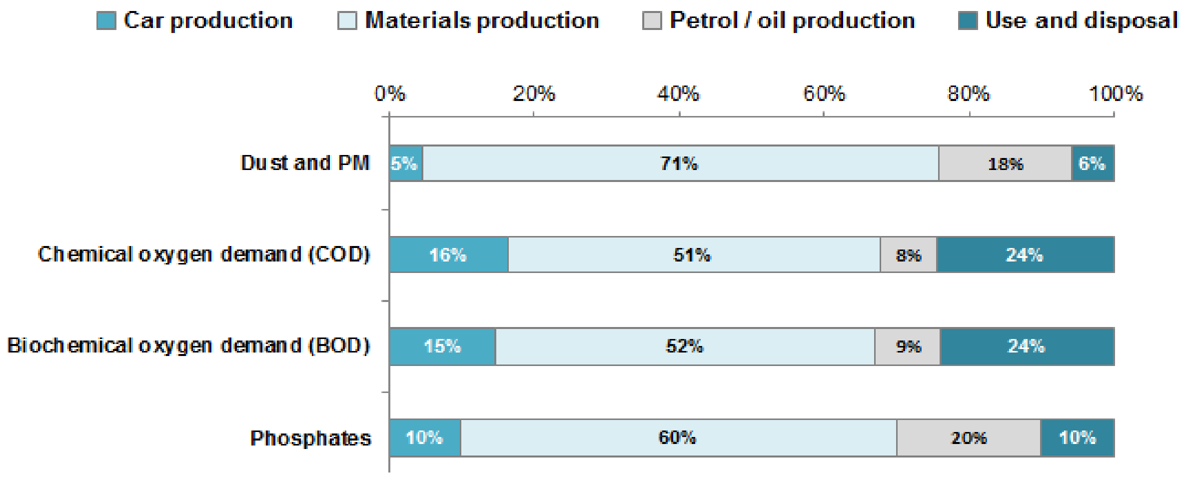
Table 3-34: Water consumption through a car's lifecycle (excluding use phase), litres per vehicle

Lifecycle phase	Water use	%	Water consumption	%
Material production	169,212	80%	5,570	68%
Parts production	34,956	17%	894	11%
OEM assembly/production	4,550	2%	1,490	18%
Recycling	3,039	1%	259	3%
Total (excluding use phase)	211,757		8,213	

Source: (Bras et al, 2012)*, based on literature values*

Figure 3-16 shows the lifecycle emissions from a Golf A4 (petrol version), calculated using data from 1999. Although it is likely that treatment of these emissions has improved in Europe since the publication of this study, it still gives an indication of the relative importance of materials production in the generation of particulate matter (PM), chemical oxygen demand, biochemical oxygen demand and phosphates.

Figure 3-16: Emissions from a Golf A4 with 55 kW Otto engine



Source: (Schweimer, 2000)

Due to the importance of these processes, further recommended guidance is outlined in Box 3-6

Box 3-6: Recommended guidance for best practice in smitheries, foundries and general metal fabrication

General best practices are covered under guidance on the **Best Available Techniques Reference Document (BREF) for the Smitheries and Foundries Industry**, which includes:

- Pattern making;
- Raw materials storage and handling;
- Melting and metal treatment;
- Mould and core production;
- Casting or pouring and cooling;
- Shake-out;
- Finishing;

- Heat treatment.

For the latest available version, please refer to the online repository[26].

A forthcoming **Sectoral Reference Document on *Best Environmental Management Practices for fabricated metal products*** will cover many generic processes relevant to metallic components. This will provide guidance on how to minimise the environmental impacts of most generic processes that are used in the production of metallic vehicle components.

This document will be available on the JRC's website[27].

3.5.4.3 Paint shop operations

The paint shop is one of the most significant processes in terms of environmental impacts in a car assembly plant. Environmental impacts include:

- Significant contribution to total energy consumption (Sullivan, 2010). Depending on the processes involved, painting systems can account for up to half of total electricity consumption (Galitsky & Worrell, 2008), or if infra-red drying is not used then natural gas can be consumed (Schweimer, 2000);
- Specific figures with respect to the proportion of total waste arising from the paint shop were not available, but the painting process has been specifically mentioned as a significant source of waste in several publications including (Ai Group, no date), (Environment Australia, 2002) and (Volkswagen, 2012);
- Water consumption from paint operations can account for 60-70% of water use in a plant (Toyota, 2012a);
- VOC emissions from painting have relatively high impacts (Renault, 2011).

Due to the importance of the paint processes, dedicated guidance has been developed in a separate document. Please refer to Box 3-7.

Box 3-7: Recommended guidance for best practices in automotive painting operations

Guidance on **Best Available Techniques Reference Document (BREF) for Surface Treatment Using Organic Solvents**, which covers the painting of car bodies and components, including:

- Selection/substitution of paint types including low-solvent paints;
- Pre-treatment techniques;
- Paint application techniques and equipment to reduce emissions and energy consumption;
- Drying techniques;
- Waste gas and water treatment.

At the time of writing, the existing document is currently undergoing revision. For the latest available version, please refer to the online repository[28].

A separate **BREF on the Surface Treatment of Metals and Plastics** is also relevant to paint shop operations.

3.5.4.4 Electrical and electronic equipment

The increasing levels of electrical and electronic equipment in modern vehicles means that the environmental impacts of these components is growing. For example, electronics were identified as having >10% impact on SO_2 emissions in some Mercedes vehicles, due to the use of non-ferrous metals (Mercedes, 2009).

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[26] http://eippcb.jrc.ec.europa.eu/reference/
[27] http://susproc.jrc.ec.europa.eu/activities/emas/
[28] http://eippcb.jrc.ec.europa.eu/reference/

It is highly recommended that manufacturers consider the guidance outlined in Box 3-8, which covers general issues relating to best practice in electronics and electrical equipment manufacturing.

Box 3-8: Recommended guidance for best practice in the manufacture of automotive electronics and electrical equipment

A forthcoming **Sectoral Reference document on *Best Environmental Management Practices for the manufacture of electrical and electronic equipment*** will cover processes that are applicable to many automotive electronic systems.

This document will be available on the JRC's website[29].

3.5.4.5 Minimising releases of hazardous or polluting fluids

During production, new vehicles are filled with various fluids (including fuels, lubricants, refrigerants etc.), some of which could be harmful to the environment. In addition, various production processes require fluids for operation – including the use of lubricants and cooling fluids.

Primarily, measures to minimise the use of hazardous fluids should be investigated. Potential options in the automotive sector include:

- **Introduction of processes requiring lower levels of emulsions or cooling lubricants.** However, the integrity of production processes must be maintained when considering options to reduce or change lubricants. For example, inadequate damping of press machinery can lead to damage to buildings due to excessive vibration (Volkswagen Group, 2007);
- **Biodegradable hydraulic oils** may be used wherever possible or economically reasonable.

Where the relevant substances cannot be avoided, measures must be implemented to ensure that storage, handling and transfer of these fluids is managed to prevent releases to the environment. For example, Volkswagen has mandated the "2-barrier" principle at all plant and storage facilities housing fluids that are potentially harmful to the environment, as well as monitoring of leak tightness (Volkswagen Group, 2007). The choice of refrigerants used in mobile air conditioning devices is the subject of separate regulations, but proper storage and transfer of the refrigerant should be ensured to avoid emissions.

For further guidance, readers are referred to the guidance outlined in Box 3-9.

Box 3-9: Recommended guidance for best practice with respect to minimising releases of hazardous or polluting fluids used in automotive manufacturing

The guidance on **Best Available Techniques Reference Document (BREF) for Emissions from Storage** provides detailed information on the storage, transfer and handling of liquids, liquefied gases and solids (regardless of the sector or industry). It addresses emissions to air, soil and water.

This document is available online[30].

Although proper storage, transfer and handling should minimise releases, they may not be entirely preventable – in which case, the hazardous or polluting substances must be captured and treated. The guidance on **Best Available Techniques Reference Document (BREF) for Waste Treatment Industries** provides guidance on treatment, filtration and management of wastes in gases, water and soil.

This document is available online[31].

3.5.4.6 Manufacturing of other key components and materials

Guidance for the manufacturing of trim, glazing, plastics, textiles and other relevant materials is included in **Best Available Techniques Reference Documents (BREFs)** for the following sectors:

- Tanning of hides and skins;

[29] http://susproc.jrc.ec.europa.eu/activities/emas/
[30] http://eippcb.jrc.ec.europa.eu/reference/BREF/esb_bref_0706.pdf
[31] http://eippcb.jrc.ec.europa.eu/reference/BREF/wt_bref_0806.pdf

- Manufacture of glass;
- Ferrous metals processing industry;
- Ceramics manufacturing industry;
- Industrial cooling systems (cross-cutting);
- Iron and steel production;
- Management of tailings and waste-rock in mining activities;
- Manufacture of glass;
- Non-ferrous metals industries;
- Production of polymers;
- Smitheries and foundries industry;
- Surface treatment of metals and plastics;
- Textiles industry;
- Waste incineration.

For the latest documents, please refer to the online repository[32].

3.5.4.7 Reference literature

Ai Group. (no date). Managing waste in the automotive (components) manufacturing industry. Available at: http://pdf.aigroup.asn.au/environment/16_Automotive_Manufacturing_Waste_Reduction_Factsheet.pdf (accessed 06/02/2014).

BMW. (2012). Sustainable values report. Available at: http://www.bmwgroup.com/e/0_0_www_bmwgroup_com/verantwortung/svr_2012/index.html (accessed 01/02/2014).

Bras et al. (2012). Quantifying the life cycle water consumption of a passenger vehicle. SEA International. Available at: http://www.manufacturing.gatech.edu/sites/default/files/uploads/pdf/2012-01-0646_0.pdf (accessed 01/02/2014).

Environment Australia. (2002). Environmental Impact of End-of-Life Vehicles: An Information Paper. Available at: http://www.environment.gov.au/archive/settlements/publications/waste/elv/impact-2002/chapter12.html (accessed 30/01/2014).

Galitsky, C., & Worrell, E. (2008). Energy efficiency improvement and cost saving opportunities for the vehicle assembly industry. Berkley National Laboratory.

Mercedes. (2009). Life cycle environmental certificate for vehicle models (available from manufacturer website).

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Toyota. (2012a). Water efficiency at Toyota Motor Europe. Available at: http://www.ceps.eu/files/Presentation_Water_Toyota.pdf (accessed 08/04/0214).

Volkswagen Group (2007) Environmental group protection principles: production plant. Available at: http://sustainability-report2012.volkswagenag.com/fileadmin/download/24_Umweltgrundsaetze_Produktion_e.pdf (accessed 10/06/2014)

Volkswagen. (2012). Sustainability Report. Available at: http://nachhaltigkeitsbericht2012.volkswagenag.com/fileadmin/download/pdf/VWAG_NHB_2012_e_online.pdf (accessed 14/01/2014).

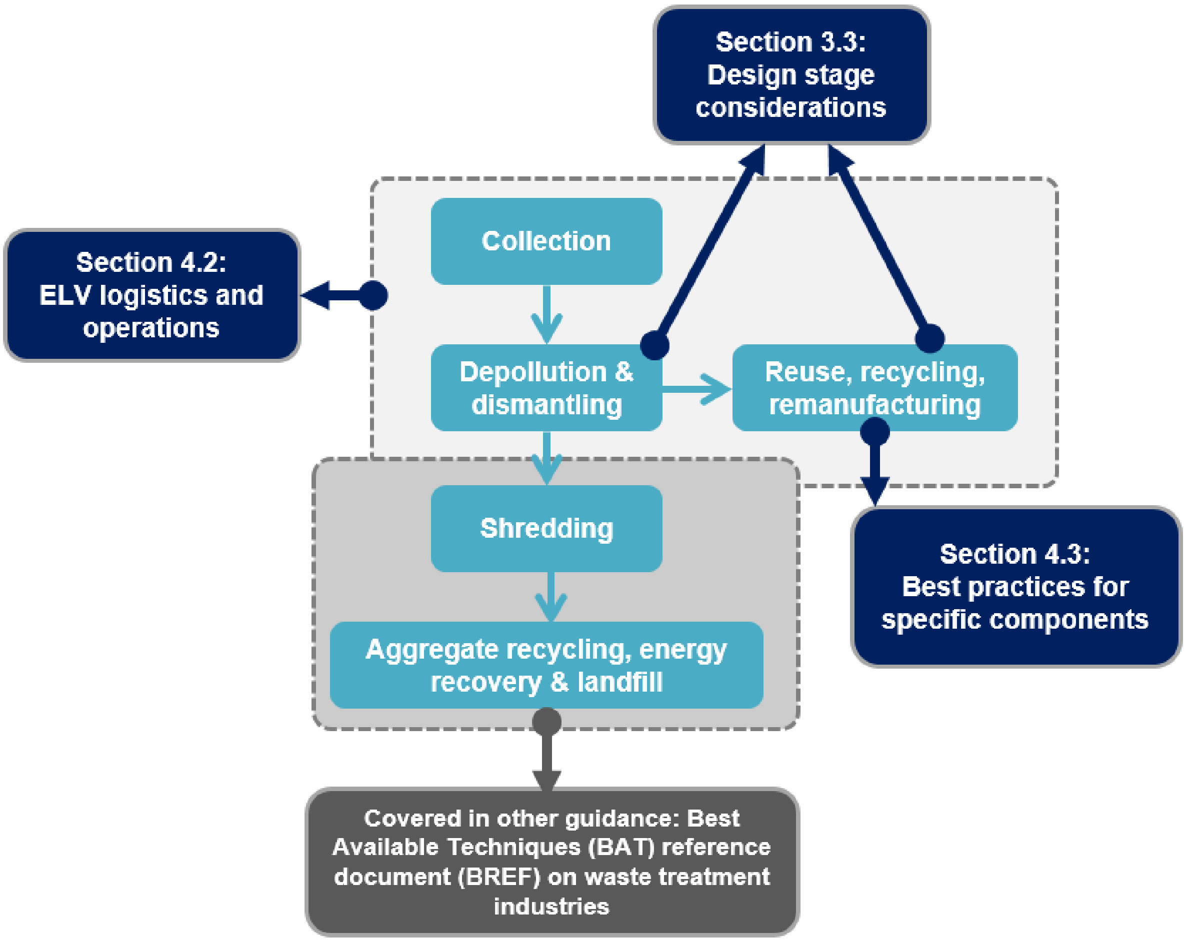
[32] http://eippcb.jrc.ec.europa.eu/reference/

4 Best environmental management practices for the treatment of end-of-life vehicles

4.1 Introduction: Chapter scope

The scope of best practices for the treatment of end-of-life vehicles (ELVs) covers operations that take place before the vehicle is shredded. Once the vehicle hulk reaches the shredder it is typically mixed with other waste streams and subject to more general recycling and recovery operations that are covered in other general guidance[33]. An overview of the main topic areas is shown in Figure 4-1.

Figure 4-1: Overview of topic areas covered



The energy consumption and GHG emissions associated with the dismantling and recycling of vehicles is a small portion of the total life cycle impacts (Renault, 2011), typically accounting for around 1% of total life cycle emissions, and less than 6% of the life cycle stages excluding the in-use phase. However, while the recycling processes do not consume significant energy themselves, the processes at the ELV stage can still influence overall energy consumption when considering the materials that are avoided.

[33] . See the *Reference Document on Best Available Technologies for waste treatment industries*.

Recycling of ELVs is a complex process - the composition of vehicles changes constantly, while waste treatment technology is steadily improving. At the end of a product's life there can be several options for its processing including reuse, remanufacturing, reconditioning, repair etc. For clarity, it is important to note that there are differences between these processes – even though these terms may sometimes be used interchangeably in literature. Definitions of these types of product recovery are outlined below, ordered from least to most intensive (EPA, 2014):

- **Reuse** implies parts that have been previously used (but are not defective) are supplied to other customers with little or no changes. In this instance the part can be used directly as long as it meets safety standards. Due to this limitation, used parts that have not been repaired in any way are generally not easily available;
- **Repair** typically involves repairing defective aspects of a vehicle part so that the unit functions properly again, but without extensive rebuilding. It is therefore a less significant intervention, because the part has not usually been completely disassembled – i.e. it effectively extends the useful life of a product;
- **Reconditioning/refurbishing** is the process of restoring a component to a functional level. Typically it differs from remanufacturing in that none of the structural parts of the product are replaced. Rather, it tends to involve less intensive processes such as resurfacing and repainting;
- **Remanufacturing** is also known as "rebuilding". This involves restoring components to a "new" condition by repairing or replacing worn or damaged parts;
- **Recycling** involves processing the component and then returning it to the industry in the form of raw materials, semi-materials (transformed to some degree) or re-melting into a new finished good.

4.2 ELV logistics and operations

4.2.1 Section overview and technique portfolio

The focus of this section is on the operational aspects of ELV management. Several common challenges are faces by firms when attempting to reduce the environmental impact of ELVs – such as improving cost-effectiveness, reliability and managing the coordination between many different stakeholders. Techniques in this section therefore provide guidance on how frontrunner organisations have successfully managed these complex issues.

The range of stakeholders involved in managing ELVs includes manufacturers, repairers, recycling plants, dismantling facilities, shredders and waste management firms. Guidance in this section generally covers activities involving several of these actors.

The main themes are:

- **Component and material take-back networks**: Establishing effective collection networks is an important enabling factor to allow greater recovery, reuse and recycling of ELV components and materials.
- **General best practices for remanufacturing components**: Remanufacturing involves dismantling and repair of used vehicle parts to restore their performance to a level comparable to new parts. While this has taken place on a relatively small scale in Europe for many years, this BEMP provides guidance on best practices to scale up activities.
- **Equipment sharing networks for SMEs** - The depollution and dismantling sector is typically made up of many small organisations, who may not have the resources to invest in the latest equipment or knowledge of best practices. Benefits may be expected from establishing such networks

4.2.2 Component and material take-back networks

SUMMARY OVERVIEW:				
Effective take-back networks employed by frontrunner organisations can increase the rate of reuse, recycling and recovery that is economically achievable when treating ELVs. This involves extensive collaboration between different industry actors to recover components, consolidate with other waste streams where possible as well as training and support.				
Relevant lifecycle stages				
Management	Design	Supply chain	Manufacturing	**End-of-life**
Main environmental benefits				
Energy consumption	**Resource use and waste**	Water use & consumption	Emissions to air, water, soil	Ecosystems & biodiversity
Environmental indicators				
• Recovery rate (%) for specific products or materials through ELV networks				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Design for sustainability using Life Cycle Assessment			
Related BEMPs	• General best practices for remanufacturing components • Best practice ELV treatment for specific components			

4.2.2.1 Description

Effective collection networks are one of the most important mechanisms to enable full exploitation of recovery, reuse and recycling options. Collection systems aim to take back specific components or ELVs and ensure they are properly treated.

The lack of an effective and economical collection system for separate components is one of the main barriers for increased recycling and reuse. While in some cases post-shredder treatment can be the most environmentally benign option, better collection networks would improve the life cycle environmental impacts for some components (ADEME, 2008) (Farel et al, 2013).

For whole vehicles, collection networks are a requirement under the End-of-Life Vehicle Directive, although the implementation method is not prescriptive. Therefore, the guidance in this section provides an overview of best practices, taking into account that organisations may be working within the constraints of different national situations. The ELV collection systems can be of two broad types:

- **Individual systems** in which each manufacturer is responsible for collection of their own brands through bi-lateral relationships and contracts.
- **Collective systems,** where different brands are collected through the same network. Although the End-of-Life Vehicle Directive requires that Member States establish collection systems for ELVs, there are several barriers to implementation including complex administrative requirements, lack of public awareness and additional costs.

The majority of Member States have both types of network. The dominant situation in each Member State varies due to different historical experiences, administrative arrangements and approaches to implementing the End-of-Life Vehicles Directive.

This general framework for best practice is primarily aimed at collection of components rather than whole vehicles, but is also generally applicable. It consists of the following stages:

- **Collaboration with industry actors:** In order to implement an integrated approach to material reuse, links must be established between those responsible for the design of products, their production and the management of waste once the product has reached the end of its life. This includes manufacturers and importers of vehicles, part manufacturers/suppliers, recycling plants, dismantling stations, shredders, car collection

points and waste management firms (BIO Intelligence Service, 2013). This is vital to coordinate the tracking, collection and transportation of components and materials and to ensure that the **right incentives** are in place for actors in the chain.

- **Managing/incentivising product return:** In addition to collaborative efforts with industry actors, there are several possible business models that could encourage easier management of product return.
- **Consolidation with other waste streams:** Synergies with other components can be exploited to reduce the administrative burdens and pool expertise.
- **Providing technical support and awareness-raising:** Awareness-raising activities should be undertaken regularly, as lack of awareness is a key barrier to component recovery.

4.2.2.2 Achieved environmental benefits

The environmental benefits of establishing the collection systems are not directly quantifiable, as it depends on the subsequent treatment steps. Rather, this best practice is a prerequisite for unlocking higher reuse, remanufacturing, recovery and recycling potential by ensuring that the parts are collected effectively. Effective collection systems would also make it easier to avoid the black market dismantling sector, which can involve poor depollution practice and consequent soil and water pollution (MVDA - personal comm., 2014).

4.2.2.3 Environmental indicators

- Recovery rate (%) for specific products or materials through ELV networks.

4.2.2.4 Cross-media effects

Systems should be designed so that the life cycle impacts are minimised (see also *Section 3.3.2: Design for sustainability using Life Cycle Analysis (LCA))*. Improving the collection of components is likely to lead to higher emissions from transportation and energy consumption during any subsequent processing steps that are enabled.

In a scenario which results in the increased transportation of ELVs and their components, it will be critical to ensure that fluids are effectively removed from the ELVs, in order to minimise potential pollutant emissions to soil and water (ARN - personal comm., 2014).

4.2.2.5 Operational data

The best practice examples focus around increasing the rate of recovery of products (through improving product tracking, collaborative efforts and awareness-raising), as well as reducing costs by consolidating waste streams. Examples of best practice implementation include:

- **Collaboration with industry actors:** Renault works with recyclers and waste management companies—including INDRA (who manage distribution, treatment and recovery of ELVs). They have also formed a joint venture with a steel recycler to collect materials for recycling from their plants and other end-of-use parts. This gives them greater control of the material flow and allows them to ensure higher quality (World Economic Forum, 2014).
- **Managing/incentivising product return:** The most appropriate model depends on the customer segment and the product involved, and may include the following examples (World Economic Forum, 2014):

- **Trade-ins:** when selling a new product, the customer is offered a trade-in price for his redundant product. The trade-in price is often given as a discount on the new product sale. This may be appropriate for items such as worn or part-worn parts (such as gearboxes, brushes for electric motors etc.).
- **Leasing business models:** where the product is leased to the consumer for a given period, after which the product is returned. This has been offered for management of vehicle fleet tyres for decades, but may also be applicable to other areas.
- **Removal / disposal services:** for products that do not have a high residual value, removal services may be appropriate to recover redundant products. ELV take-back networks are a typical example.

Crucial aspects to consider are the extent of product variety being returned and hence the extent to which the process can be automated, as well as the distances to be travelled.

- **Consolidation with other waste streams:** Synergies with other components such as batteries, tyres, electronics, airbags etc. can be exploited to reduce the administrative burdens and pool expertise. For example, reuse of components is typically only possible if they are replaced in the same vehicle model, except for some low-value components such as hose clips.
- **Providing technical support and awareness-raising:** Awareness-raising activities should be undertaken regularly to ensure that both consumers and firms are aware of the collection network. Technical support is particularly important for the ELV dismantling sector, which typically has many small actors with limited resources to keep up to date with current best practices or legislative changes (Optimat, 2013).

4.2.2.6 Applicability

The greatest potential environmental gains appear to be in collecting advanced technologies with limited service life (such as hybrid or electric vehicle batteries), as well as components/materials that are less financially attractive to dismantle (such as plastic and glass components) (Optimat, 2013).

Collection networks can apply to whole vehicles or specific components. With respect to managing/incentivising product return, the applicability of alternative business models (if at all) depends on local regulation, the customer base, the geographic dispersion and the type of product involved. However, the overriding factor is that the marketing of spare parts is an informal market, which typically depends on the dismantler's knowledge of which parts can be used in which vehicles, and whether there is a demand for those parts (ARN - personal comm., 2014).

There is currently a lack of information amongst ATFs, on how to appropriately deal with vehicle parts at end-of-life. Modern vehicles contain increasingly complicated technology and ATFs have relatively little understanding of how to deal with complex parts through reuse, remanufacturing or recycling (EGARA - personal comm., 2014). The International Dismantling Information System (IDIS) covers material information but does not, as yet, provide access to useful information on parts (in particular – part numbers for identification) (EGARA - personal comm., 2014), (MVDA - personal comm., 2014).

In some EU countries, take back schemes could be restricted by competition from the black market sector for dismantling of ELVs; one expert estimates that ~25% of ELVs disappear in the UK every year (MVDA - personal comm., 2014). Although OEMs can endeavour to select the most environmentally friendly dismantlers, the incentives for dismantlers to actually implement best practice are removed by competition with black market dismantlers, which can dispose of vehicles more cheaply by avoiding even legislated environmental practices (Toyota - personal comm., 2014).

4.2.2.7 Economics

In general, the cost of collection and treatment of ELVs is covered by the revenues from recycling (BIO Intelligence Service, 2013). Additional fees may be needed to cover data reporting, audits and communication/awareness-raising actions (BIO Intelligence Service, 2013).

Establishing closed-loop recycling can also help to reduce risks due to increases in prices and volatility in raw materials (World Economic Forum, 2014).

The issue of creating the right economic incentives for actors in the supply chain is important, and one of the key factors that can determine the success of a scheme. Examples of successful schemes

include the use of "recycling fees" in Japan. Producers have responsibility to take back and recycle components, with all items monitored and traceable through electronic records (Kitgawa, 2010).

4.2.2.8 Driving force for implementation

An important driver for collection of whole vehicles is the ELV Directive. National legislation is typically based on this Directive. At the manufacturer level, establishing closed-loop recycling for products is driven by increasing prices and volatility of raw materials (World Economic Forum, 2014).

4.2.2.9 Emerging issues

Since hybrid and electric vehicles are relatively new to the market, few have been processed as ELVs (MVDA - personal comm., 2014). Initial indication of best practice with respect to battery collection is shown in Table 4-1

Table 4-1: Examples of best practice implementation

Best practice	Examples
Managing / incentivising product return	Renault became the first car maker to lease batteries for electric cars to help retain the residual value of electric vehicles (to encourage higher consumption) and make batteries fully traceable, ensuring a high collection rate for closed-loop reengineering or recycling (World Economic Forum, 2014). For tyres, Michelin pioneered leasing for fleets.
Consolidation with other waste streams	Components that need to be replaced during a vehicle's lifetime are collected from retailers and workshops. Toyota consolidates collection of vehicle batteries with catalysts and returning delivery trucks of Toyota service parts (Toyota, 2013).
Providing technical support and awareness-raising	Toyota provides a 24-hour helpline to receive collection requests for its hybrid vehicle batteries (Toyota, 2013). Awareness-raising activities should cover a range of different media in order to reach a wide audience, including radio, social media, internet, magazines and other publications. These are regularly carried out by ELV collection networks across Europe (BIO Intelligence Service, 2013).

In some countries there is no widespread commercial system for collecting hybrid batteries, and dismantlers are unsure how to dispose of them (MVDA - personal comm., 2014). Furthermore, the movement of electric vehicle batteries are governed by strict legislation under the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), which make the costs of collection excessively expensive when they are in compliance with ADR regulation (ARN - personal comm., 2014).

4.2.2.10 Reference organisations

See operational data for details: Toyota (Toyota, 2013) and Renault (World Economic Forum, 2014).

4.2.2.11 Reference literature

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4.2.3 General best practices for remanufacturing components

SUMMARY OVERVIEW:				
Achieving greater levels will have a significant impact on the conservation of materials and energy savings. This BEMP is focussed on methods to increase the scale of remanufacturing activities in the automotive sector - frontrunner organisations have established procedures to ensure high quality of remanufactured parts while reducing environmental impacts and scaling up activities to cover more components.				
Relevant lifecycle stages				
Management	**Design**	**Supply chain**	Manufacturing	**End-of-life**
Main environmental benefits				
Energy consumption	**Resource use and waste**	Water use & consumption	Emissions to air, water, soil	Ecosystems & biodiversity
Environmental indicators				
• Weight per component (%) • Overall remanufacturing levels (% of recovered components).				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Design for sustainability using Life Cycle Assessment			
Related BEMPs	• Best practice ELV treatment for specific components			

4.2.3.1 Description

Components that are often economical to remanufacture include many mechanical and hydraulic parts, as well as a growing number of electrical/electronic parts. Examples include (Optimat, 2013):

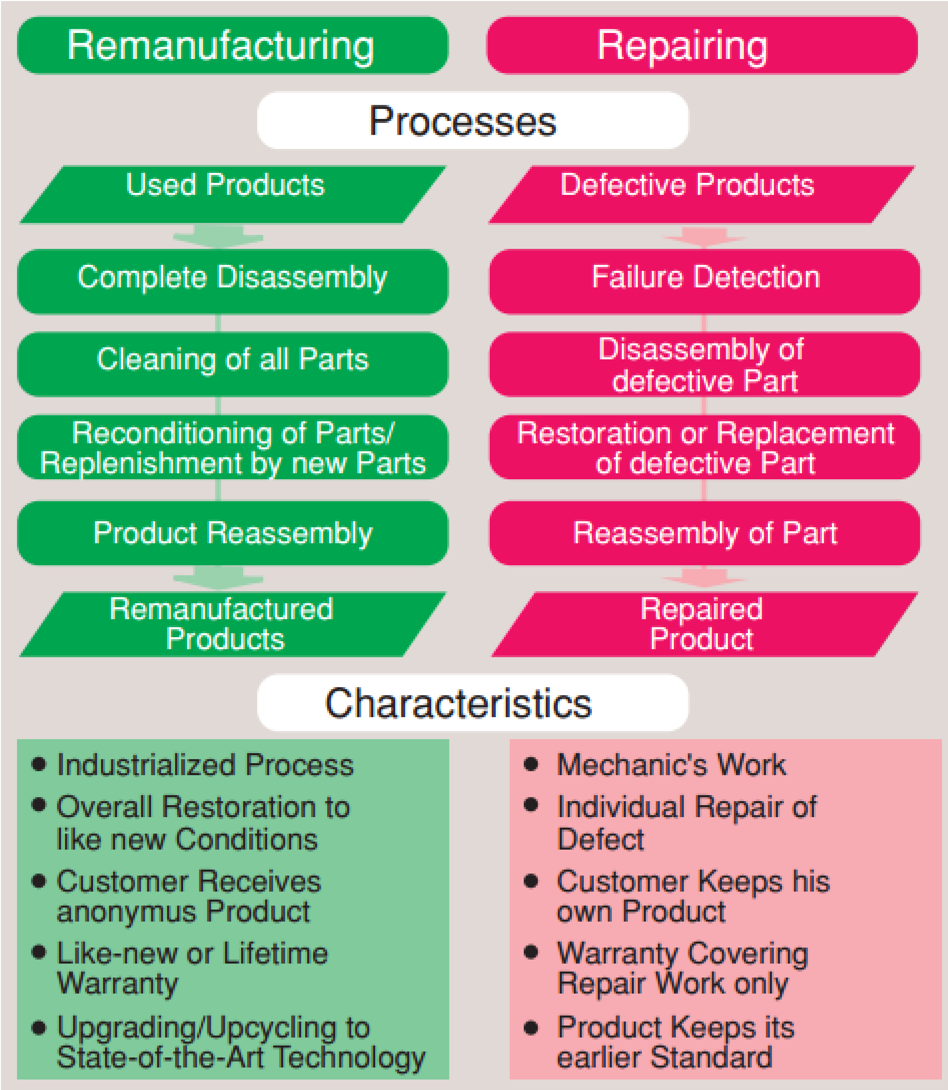
- Air Conditioning Components
- Air brakes
- Alternators
- Brake Callipers
- Carburettors
- Clutches
- Cylinder heads
- Driveshafts
- Electrical units, Instrument Clusters & Controllers
- Engines and engine components
- Fan motors
- Heater blowers
- Front axles
- Fuel pumps
- Fuel injectors and ignition
- Generators
- Gearboxes
- Master cylinders
- Pumps (hydraulic, oil, water
- Rack and pinions
- Radiators
- Starters, alternators
- Steering units (manual, power)
- Turbochargers
- Torque convertors
- Transmissions

Remanufacturing involves dismantling and repair of used vehicle parts to restore their performance to a level comparable to new parts. Typically it involves:

1. Completely dismantling the used part (see *Section 5.1.2: Design for dismantling*);
2. Cleaning all components;
3. Checking these components, repairing or replacing defective components, replacing missing components;
4. Reassembling the part, readjusting as necessary and submitting it to a final test.

This process is outlined in Figure 4-2, which also highlights the distinction between remanufacturing and recycling (see the introduction to Section 4 for definitions).

Figure 4-2: Remanufacturing process for automotive components compared to repair process



Source (Steinhilper, 2010)

Step 1: Completely dismantling the used part

See *Section 5.1.2: Design for dismantling* for guidance.

Step 2: Cleaning all components

The cleaning step involves de-greasing, de-oiling, de-rusting and freeing the parts from old paint. Methods include washing in cleaning petrol, hot water jet or steam cleaning, chemical detergent spraying or chemical purifying baths, ultrasonic cleaning chambers, sand blasting, steel brushing, baking ovens and many more. This step can be made more environmentally friendly by moving to newer and more efficient cleaning technologies that do not generate hazardous wastes (Steinhilper, 2010). Best practice techniques:

- Do not involve the use of chemical detergents, replacing these instead with less harmful products such as water soluble detergent (Steinhilper, 2010);
- Use mechanical cleaning where possible, such as by glass bead or steel shot blasting (Steinhilper, 2010). These processes also help to harden the surface, thereby improving

resistance against abrasion of the remanufactured product's parts (but may change the tolerances for bearings etc.).

Step 3: Checking these components, repairing or replacing defective components, replacing missing components

The third stage is to sort the disassembled materials. This process may be significantly helped by using tools such as screw gages to measure and compare screw dimensions instead of visual inspection, as well as greater standardisation efforts in the manufacturing industry (Steinhilper, 2010).

Some facilities also redesign components (such as gearboxes) to increase the reuse ratio and make sorting easier by standardising components (European Commission, 2012).

Step 4: Reassembling the part, readjusting as necessary and submitting it to a final test

Remanufacturing applies many of the same principles as original manufacturing, including experience with machine tools, assembly equipment and quality assurance. Equipment for reconditioning (such as lathes, milling and drilling machines) are similar to those used in manufacturing original equipment, undergo the same tests and often come with the same warrantee (Steinhilper, 2010).

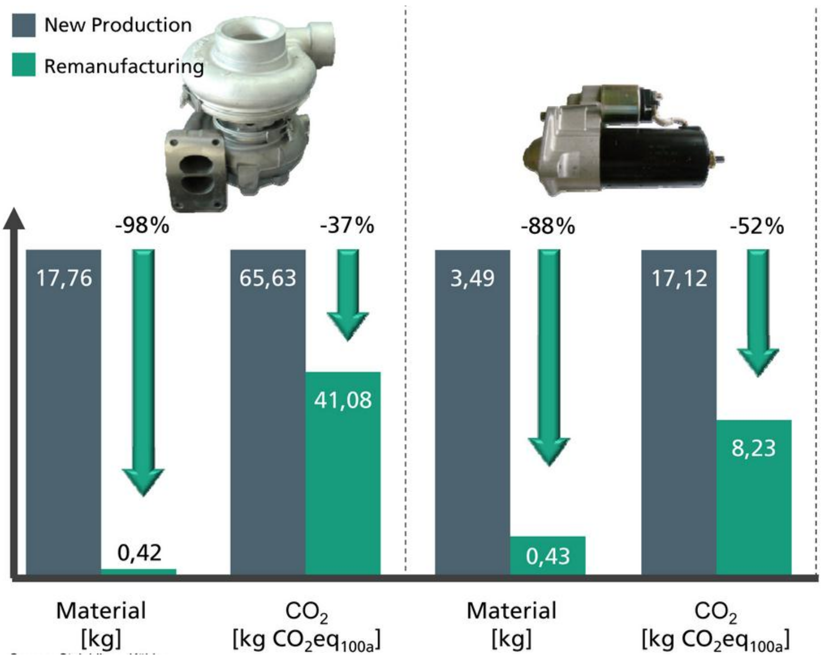
A further aspect that may improve overall environmental achievements is awareness-raising around the correct procedures to dismantle components. For example, many diesel particulate filters that are initially sound are damaged during the removal and/or transportation process – according to one source this is assumed to be because the value of the cores is not recognised (Sundin & Dunbäck, 2013). The impact is increased scrap rates of cores that were originally suitable for remanufacturing (Sundin & Dunbäck, 2013).

4.2.3.2 Achieved environmental benefits

In all cases, the suitability of a part for remanufacturing versus other ELV treatment should be assessed on a life cycle basis. These often include mechanical and hydraulic parts, where only parts of the component might fail, as well as a growing number of electrical/electronic parts.

The remanufacturing industry helps the environment through raw material conservation and energy reduction. The use of remanufactured parts and components can conserve up to 85% material and energy use compared to new parts (Optimat, 2013) – see Figure 4-3.

Figure 4-3: Example material and CO_2 savings from use of remanufactured parts



Source: (Optimat, 2013)

Further environmental benefits can also be expected in terms of water consumption, chemical usage and waste. Renault estimates that their remanufacturing operations offer significant benefits in terms of the following (Ellen MacArthur Foundation, 2013):

- 88% less water is required compared to manufacturing products from new;
- 92% fewer chemical products are used;
- 70% less waste is generated.

4.2.3.3 Environmental indicators

In general, the less a product has to be changed, the quicker it can return to the market and the greater the savings in terms of energy and materials (and associated environmental impacts) (Optimat, 2013). Monitoring of this BEMP can be divided into the level of remanufacturing in terms of weight per component (%) as well as overall remanufacturing levels (% of recovered components).

Since a life cycle approach is recommended to evaluate the savings, the same indicators may be used (see *Section 3.3.2: Design for sustainability using Life Cycle Analysis (LCA)).*

4.2.3.4 Cross-media effects

No significant cross-media effects are expected. However, remanufacturing of parts may present logistical conditions which require delivery fleet vehicles to travel greater distances, resulting in higher GHG emissions; careful planning and logistics management can be used to negate some of the environmental impact of new and additional transport to and from remanufacturing sites (Toyota - personal comm., 2014).

4.2.3.5 Operational data

Remanufacturing can have a significant impact on the conservation of materials, energy use, and emissions of GHGs. It has been taking place in Europe for decades, carried out by both independent remanufacturers and OEMs; however, general levels remain at a relatively small scale due to various challenges. Firstly, some components tend to have a relatively low value for the dismantler. For example, a brake calliper remanufacturer will be selective in which brake callipers it accepts and will pay little to get them, whereas it can be costly for a dismantler to remove and store the part (MVDA - personal comm., 2014).

Furthermore, there has traditionally been a poor linking of demand to supply; remanufacturers might request dismantlers to remove and store a part, which they would then not collect as the demand had changed (MVDA - personal comm., 2014). It is crucial that the correct cores in the right quality are available to the respective remanufacturing factory at the right time and in the right volume. This issue has been exacerbated by trends towards more variants and shorter model systems, making it more difficult to match parts to specific vehicles, as well as the difficulty of forecasting due to uncertainties over timing and quantities of returned products (Sundin & Dunbäck, 2013).

However, recent developments in ICT are empowering ATFs (including SMEs) to overcome these obstacles. Software in use by remanufacturing organisations such as Premier Components UK, allow ATFs to use a vehicle's license plate number to access a database revealing the demand for, and price of, relevant parts/components of the ELV in question (MVDA - personal comm., 2014). Systems such as this have led to increased rates of remanufacturing (MVDA - personal comm., 2014). Another example of an ICT system is the CoremanNet return system (Core-Management Network), which was specially developed to this purpose more than ten years ago, and is now an established network with sixteen collection and evaluation points in Europe, USA and China. According to the developers, CoremanNet enables a successful remanufacturing business and the resulting saving of 23,000 tons of CO_2 annually in comparison to the production of new automobile replacement parts (CoremanNet, 2014)

Whilst there is likely to continue to be a role for small businesses to participate in the remanufacturing economy, larger-scale remanufacturing services can achieve specialisation and economies of scale, which helps to overcome some of these key barriers.

Ensuring quality and consumer acceptance can be an issue in some cases, if the product is perceived to be inferior or unsafe. Industry standards and certification are a significant issue in this respect –

although it is expected that the development of standards such as the British Standard for remanufacturing (BS 8887-220:2010) will help to overcome these issues (Optimat, 2013).

4.2.3.6 Applicability

Currently, remanufactured parts and components are mainly supplied to the aftermarket (i.e., for repairs and maintenance rather than new vehicles). However, there are examples of remanufacturing sites being established near new vehicle production sites for the purpose of supplying parts and components for use in new vehicles (at least in part) – such as Renault's facility at Choisy-Le-Roi (European Commission, 2012). The site has several hundred employees, who remanufacture engines, transmissions, injection pumps gearboxes and turbocompressors. Its output is still delivered primarily to the aftermarket division, but some components are supplied for new vehicles (European Commission, 2012). Renault works with its own distributor network to obtain cores, and supplements these with used parts purchased directly from end-of-life vehicle disassemblers, as well as with new parts where necessary (European Commission, 2012).

Typically, remanufacturing is viable for products with higher resale values, and markets for some components are already mature (e.g. starters, alternators etc.). Other areas are at an earlier stage of development (such as electrical and electronic components) where the complexity is much greater, and there is considerable potential for market growth in these areas (APRA Europe, n.d.). However, electronic parts may have higher residual values, meaning the economic case for reuse, repair, refurbishment and remanufacture improves against the alternative of material recycling.

Essential factors that influence the economic case for remanufacturing include (Steinhilper, 2010):

- Sales volumes of the vehicle model;
- Years of production of the vehicle model;
- Scrap rate of the vehicle;
- Vulnerability of the part.

All of these factors will influence the supply and demand of cores, and thus the feasibility of operations (see discussion of economic factors below). For example, shorter vehicle design cycles mean that the in-production phase also falls, so the population of models in circulation that are suitable for remanufactured parts is smaller (EGARA - personal comm., 2014).

Remanufacturing may also be helpful in situations where previous product generations are still in the marketplace and require maintenance, but are no longer in production (Steinhilper, 2010).

4.2.3.7 Economics

Since remanufacturing starts from the used parts, rather than raw materials, it is usually believed to be more economical (Steinhilper, 2010). Cost savings may be achieved through reductions in material and energy consumption – there are limited capital expenses required for machinery, and no cutting and machining of the products, resulting in no waste and a better materials yield. As noted previously, larger companies may be able to achieve greater economies of scale and remanufacture components more cost-effectively; however there are many examples of small firms operating profitably in the market as well (Sundin & Dunbäck, 2013).

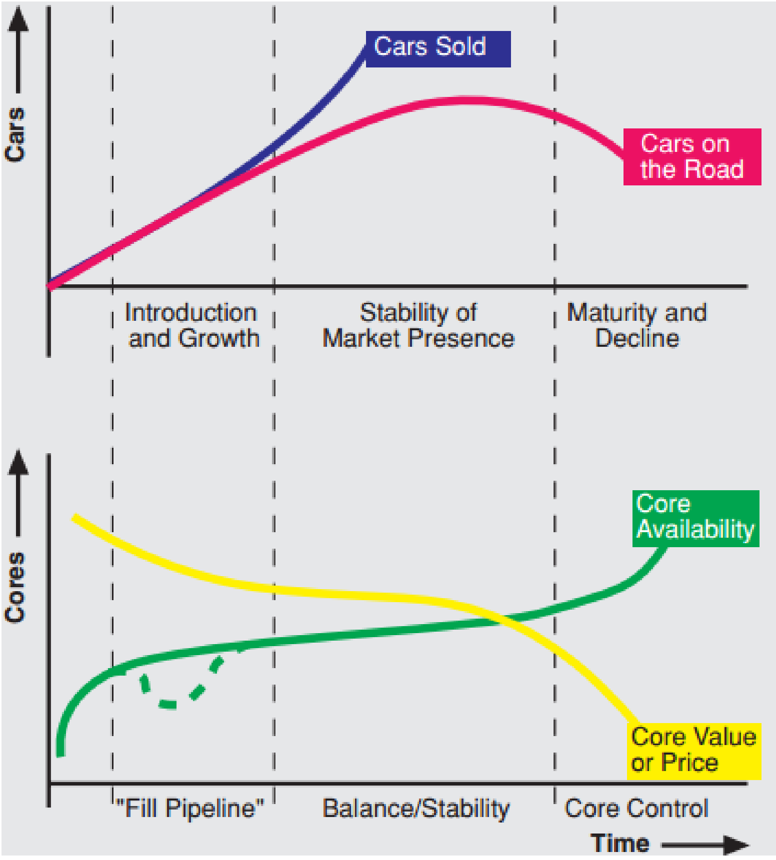
From the consumer's perspective, a remanufactured automotive part is the functional equivalent of a new part but costs typically 50-75% of a new unit and often carries the same warranty (APRA Europe, 2014). The price varies depending on the specific component, the process involved and the stage of the product life cycle.

From the remanufacturer's perspective, the main costs incurred are due to labour and purchasing of materials/parts (Steinhilper, 2010). Costs are also incurred for storage of parts and transportation. However, Renault's operations in Choisy-Le-Roi have found that remanufacturing is only economical if carried out locally (i.e. shipping parts abroad would negate the savings (Ellen MacArthur Foundation, 2013).

Generally, complex mechanical units (such as automotive transmissions and engines) require significant effort at the parts reconditioning and new parts replenishments steps (Steinhilper, 2010). Assembly costs to carry out any required repairs/replacements are typically comparable to those of new manufacturing (Steinhilper, 2010).

The cost structure of materials is highly variable; prices of cores and the residual value of equipment could vary dramatically from year to year due to multiple supply and demand issues. When a new car model enters the market, there are very few cores available – these are typically sourced from cars involved in accidents or the first units that become defective and thus the cores can be rare (if available at all) and expensive). Later in the product cycle more ELVs are available and it becomes easier to source cores. Finally, in the last market phase an excess of cores may occur leading to declining prices (Steinhilper, 2010). Figure 4-4 illustrates some of these issues. Although this is a rather simplified representation of the real world conditions, it helps to demonstrate the issues.

Figure 4-4: Core availability and value phases



Source: (Steinhilper, 2010).

4.2.3.8 Driving force for implementation

One of the main driving forces for the increase in central remanufacturing services is the End-of-Life Vehicle Directive (2000/53/EC).

However, remanufacturing operations can be profitable in their own right. For example, Toyota estimate that it will cost them less in the long-term if the vehicle parts are kept in Europe, as it facilitates local production and reduces the cost of importing parts manufactured outside the EU (Toyota - personal comm., 2014).

Renault's model has also been noted to create loyalty with clients in the brand's network, and also to facilitate the longevity of the exchange parts, at controlled costs, even for discontinued components (Ellen MacArthur Foundation, 2013). Similar rationales may apply to other OEM models.

Other drivers include: rising costs of raw materials and energy; costs or servicing aging cars and political focus (for example on job creation) (BORG Automotive, 2014).

4.2.3.9 Reference organisations

Data for some of the environmental aspects and operational information was based on Renault's Choisy-Le-Roi remanufacturing plant. There are many other actors in the remanufacturing sector, including other OEMs and independent operators.

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4.3 Best practice ELV treatment for specific components

4.3.1 Section overview and technique portfolio

The automotive sector already has a high rate of end-of-life reuse and recycling, driven largely by legislative requirements. The End-of-Life Vehicle Directive has set a target of 85% reuse and recycling and 95% reuse and recovery by 1st January 2015. Currently, the materials not reused or recovered are contained within waste output from shredders known as Automotive Shredder Residue (ASR). These are typically the most challenging components to deal with from an end-of-life perspective, and one of the key issues for the sector is how to meet these targets in the most efficient manner. The BEMPs described in this section typically involve collaboration between stakeholders in the design/manufacturing, collection, dismantling and recycling sectors.

Currently, the vast majority of metallic materials and many other valuable components (such as catalysts) from ELVs are recovered, reused and recycled efficiently. The ELV Directive also requires that certain components be removed for recycling in the dismantling stage. These include catalysts, metal parts containing copper, aluminium or magnesium, tyres, glass and large plastic components if they are not segregated in the shredding process in such a way that they can be effectively recycled. However, some of these processes (particularly involving glass, plastics and rubber) are often not economically viable for dismantlers, potentially creating compliance issues (GHK, 2006).

Therefore, this section focusses on the main areas with potential for environmental improvements, including aspects that are typically most difficult to handle at the ELV stage. Various car manufacturers differ in their approaches toward ELV management and recycling: for example, some have a primary focus on specific parts of a vehicle (e.g. Hyundai, Suzuki), while others focus on groups of raw materials (Toyota, Nissan, Ford).

Guidance in this section is divided into components/materials that may be handled in similar ways as follows:

- **Depollution of vehicles:** Since depollution is the first stage of the ELV process, it has impacts on the effectiveness of later stages such as remanufacturing and recycling.
- **General best practices for plastic and composite parts:** The range and type of plastic components in vehicles is very diverse – this section provides overarching principles to help select the best treatment methods in different situations.
- **Wiring harness – best practices for ELV treatment:** There are marked differences in approaches for the design, dismantling and subsequent treatment of wiring harnesses between different organisations. This BEMP outlines the achievements of frontrunner organisations in establishing closed loop recycling for wiring harnesses.
- **Glazing – best practices for ELV treatment:** Currently, it is typical for automotive glazing to be landfilled due to the poor economic incentives for other options. This BEMP outlines how frontrunner organisations have achieved best practices for recycling of automotive glazing in an economical manner.
- **Tyres– best practices for ELV treatment:** There are numerous possibilities for the treatment of end-of-life tyres, with differing environmental impacts. Best practices for tyres do not typically follow the traditional "waste hierarchy" and therefore more detailed guidance is provided to enable local factors to be taken into account.
- **Best practices for other automotive components and materials:** Including guidance on treatment of automotive batteries, catalysts, waste oils and fluids.

4.3.2 Depollution of vehicles

SUMMARY OVERVIEW:				
Depollution of vehicles must be carried out carefully, and where possible using specifically designed equipment. Environmental considerations are relevant to contamination ofsoil and water, but also related to the potential for recovery of materials for reuse and recycling.				
Relevant life cycle stages				
Management	**Design**	Supply chain	**Manufacturing**	**End-of-life**
Main environmental benefits				
Energy consumption	**Resource use and waste**	Water use & consumption	**Emissions to air, water, soil**	Ecosystems & biodiversity
Environmental indicators				
• Compliance with ELV Directive – removal rate of components (%) • Recovery rate of fluids (%)				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• N/A			
Related BEMPs	• Best practices ELV treatment for specific components			

4.3.2.1 Description

Since depollution is the first stage of the ELV process, it has impacts on the effectiveness of later stages such as remanufacturing and recycling. Depollution refers to the removal or neutralisation of all hazardous materials from an ELV, including batteries, liquefied gas tanks, explosive components, (e.g. air bags), fuel oil, motor oil, transmission oil, gearbox oil, hydraulic oil, cooling liquids, antifreeze, brake fluids, air-conditioning system fluids and components identified as containing mercury.

Once fully depolluted, the ELV can be stored for future removal and sale of used spare parts.

In most countries, the majority of ATFs (Authorised Treatment Facilities) use similar tools, which vary from simple hand tools, to relatively complex tools. They include (Optimat, 2013):

- Equipment which safely drills fuel tanks and hydraulically removes fuel;
- Drainage/collection equipment for oils, hydraulic fluids etc.; and to remove oil from shock absorbers;
- Tools to remove the catalytic converter;
- Equipment for removal and safe storage of air conditioning gases;
- Equipment for airbag detonation and;
- Equipment for removal of seat tensioners

The use of more complex equipment that has been specifically designed for carrying out the required depollution operations is generally considered to yield the best results as it ensures that a higher level of depollution can be achieved in a relatively short time-frame (20-30 minutes per ELV) (AEA Technology et al, 2011).

4.3.2.2 Achieved environmental benefits

The main environmental benefit achieved through the use of commercial depollution systems is an increase in the percentage of liquid removed from the vehicle (AEA Technology et al, 2011). This means that there is less hazardous substance left in the vehicle hulk, and therefore less potential to contaminate soil and water.

4.3.2.3 Environmental indicators

- Compliance with the ELV Directive
- The quantity of fluid removed (litres / %)

4.3.2.4 Cross-media effects

Commercial systems require energy in order to create the suction for liquid removal. This results in increased emissions to the atmosphere, where the energy used is derived from fossil fuels.

4.3.2.5 Operational data

One of the most popular brands in Europe is SEDA, although there are many other less well-known brands that may be cheaper and provide the same performance. These machines remove more liquids from the vehicle (including brake fluid, coolant etc.) compared to other methods such as gravity draining of fluids (EGARA, personal comm., 2014). The majority of commercial depollution equipment is operated pneumatically; therefore the compressor used to power this equipment must have sufficient capacity for satisfactory operation (AEA Technology et al, 2011).

ATFs may decide to use alternative methods to achieve the same levels of depollution, but health and safety requirements should never be compromised (AEA Technology et al, 2011). An example sequence is shown in Table 4-2, developing through practical trials in order to find a sequence that maximises the time for gravity-draining of the engine oil (AEA Technology et al, 2011).

Table 4-2: Recommended sequence of depollution operations

Operation		Description
Above vehicle	Disconnect Battery and remove from vehicle.	The SLI (starting, lighting, ignition) battery must be removed, for health and safety reasons (prevention of possible electrical discharge igniting fuel), before the fuel tank is depolluted. The battery is easily removed with standard tools. Hybrid batteries should only be disassembled by suitable qualified personnel.
	Remove fuel, oil filler, coolant, washer, brake fluid and power steering caps.	This enables the fuel, oil and other fluids to be drained more easily.
	Set heater to maximum.	This ensures that coolant in the heater unit can be drained.
	Remove wheels and tyres and separate balance weights.	Removal of wheels and tyres is not in itself a depollution activity, but may allow for easier access to drain the brakes and shock absorbers, depending on the equipment being used.
	Check for and remove any items marked hazardous (e.g. mercury switches)	Some switches, such as tilt-based switches, may contain mercury. The ELV Directive requires switches which contain mercury to be removed.
Put vehicle onto depollution frame or lifting device giving above & below access		
Below vehicle	Drain engine oil and remove oil filter for crushing or disposal	This should be done by using a suitable spanner/tool which does not puncture the oil filter during removal. The oil filter must be treated to remove residual oil. This can be achieved by crushing the filter and recovering the oil. Commercial equipment which performs this function is available. Alternatively, the oil filters can be sent to a suitable treatment facility using leak-proof transit packaging.
	Drain transmission oil, including rear differential if applicable	Transmission oil is contained in both manual and automatic gearboxes, and in the rear axle differential of rear wheel drive vehicles. If the gearbox has a drain plug, it can be gravity-drained. Gearboxes which do not have a drain plug must be drained by drilling or piercing a suitably sized hole in the bottom of the gearbox. Commercial equipment includes a suitable drill or punch, provides suction to assist in draining the gearbox, and collects the oil without the need for a container underneath the gearbox.
Above	De-gas air conditioning systems with specialist equipment	The refrigerant must be removed using specialist equipment into special canister

Operation		Description
Below	Drain coolant	Coolant can be gravity drained by removing the bottom hose from the radiator and collecting the liquid in a suitable container with a minimum volume of 10 litres. Commercial equipment enables the operator to make a hole in the bottom hose and suck the coolant out through this hole into a container. Either method can be used, but will only be able to achieve a high level of removal if the heater valve is set to maximum as part of the preliminary activities and the filler cap is removed.
	Drain brake fluid from brake lines and master cylinder	In order to achieve the required percentage of removal, brake fluid should be removed using equipment which uses suction and/or pressure on both the reservoir and the brake pipes and cylinders.
	Remove catalyst (if fitted)	Nearly all modern vehicles will have a catalytic conversion unit in the exhaust system. The catalyst unit can easily be removed by cutting through the exhaust pipe, both in front of, and behind, the catalyst unit. The use of the correct cutting equipment reduces the time which is required for this operation
Above	Drain washer bottle	Either commercially-available equipment or a simple pump can be used. If a simple pump is used, the reservoir must be inspected to determine that it has been completely emptied.
	Drain brake/clutch reservoir(s)	Virtually all modern cars have cable clutches and so do not contain any hydraulic clutch fluid.
	Drain power steering reservoir (if fitted)	If the ELV has power steering, fluid has to be extracted from both the reservoir and the connecting hose.
Below	Drain fuel tank	Fuel can be removed by suction or siphoning it from the tank with a tube entering the tank through the fuel filling pipe, but this procedure is unlikely to achieve the required level of depollution. In order to ensure that the required level of depollution is achieved, a hole should be pierced or drilled into the lowest point of the fuel tank and suction is used to remove fuel. This ensures that no vapour is released during extraction
	Drain shock absorbers or remove suspension fluid	The recommended approach is to drain the fluid from the shock absorber without removing it from the ELV. Shock absorbers contain fluid, usually oil, in both an inner and an outer cylinder. Consequently, in order to achieve the required level of depollution, fluid/oil needs to be removed from both the inner and the outer cylinder. Shock absorber fluid/oil could be removed from an ELV by removing the shock absorbers, but the time required to conduct this operation may be considerable, and the shock absorbers would be classified as hazardous waste after they were removed from the ELV.
Replace drain plugs/fit plastic stoppers, r**emove vehicle from depollution frame or lifting device and place on concrete pad**		
Above	Deploy airbags and other pyrotechnics in-situ.	The majority of airbags are electrically deployed, either from a single direct connector or a Deployment Control Unit. If it is not possible to deploy the airbag within the vehicle, remove the airbag and deploy it immediately. Commercial equipment for the deployment of all electrical pyrotechnics is available but, as different air bags use different connections, a number of adapters will be required. Pre-tensioners may contain explosive or have stored mechanical energy (large spring) that is deployed mechanically or electrically. If they contain explosive devices, they need to be deployed as part of the depollution procedure.
	Remove air bags and other pyrotechnics	It is possible for undeployed air bags to be removed and stored. However, as they are classed as explosive devices, the storage facility would have to meet all relevant regulations and requirements for storage of explosive materials, including those relating to health and safety.

Source: (AEA Technology et al, 2011)

All fluid types to be stored in separate containers in bunded storage area prior to specialist recovery/disposal. It is recommended that, where possible, air bags are deployed in situ using suitable equipment and that all persons deploying airbags attend a suitable training course (AEA Technology et al, 2011).

The Waste Oils Directive seeks to promote the regeneration of oils. Any mixing of fluids like oils may restrict the possibilities for recycling.

Finally, an important aspect of best practice concerns environmental enforcement. A best practice example comes from the Netherlands: Through co-operation between environmental enforcement authorities and ARN, effective monitoring of depollution quantities has been achieved by comparing actual depollution volumes with the weights that should have been removed in view of the amount of deregistered ELV's at a particular ATF: This methodology constitutes a "mass-balance" and is considered to be a very effective means of preventing environmental pollution (ARN – personal comm., 2014).

4.3.2.6 Applicability

Depollution rates will be affected by whether an ATF specialise in a certain type of vehicle. If an ATF specialises in larger vehicles then they can expect to retrieve a large quantity of brake fluid etc, whereas if they specialise in smaller vehicles the quantities of material to remove are more limited (EGARA, personal comm., 2014). This will influence their consideration of whether it is economically worthwhile to remove the pollutant.

Certain other factors will also be required, alongside commercial depollution machines, to ensure depollution is non-hazardous to the environment. Sites for ELV treatment and storage (including temporary storage) of end-of-life vehicles prior to their treatment must have (AEA Technology et al, 2011):

- Impermeable surfaces for appropriate areas with appropriate spillage collection facilities.
- Equipment for the treatment of water, including rainwater.
- Appropriate storage for dismantled spare parts, including impermeable storage for oil-contaminated spare parts,
- Appropriate storage tanks for the segregated storage of end-of-life vehicle fluids.

4.3.2.7 Economics

The major barrier to dismantlers using more complex equipment is the investment cost, as well as the limited value of the hazardous products removed. In the Netherlands, ARN have tried to facilitate depollution by providing commercial units to ATFs on lease (ARN, personal comm., 2014).

Commercial depollution machines are relatively expensive to install which may prohibit their use in smaller ATFs, which process less ELVs, and do not have the capital cost to invest. One expert estimated that the cost varies from €100,000 to €200,000, for installation of the machine (EGARA, personal comm., 2014).

The cost will also depend on the equipment required (e.g. vehicle ramps, working platforms, tilting ramps, storage tanks, connection, compressors etc), which is in turn dictated by factors such as the number of vehicles processed per day and the space available to the ATF (SEDA, n.d.). The capital cost of such an installation will also depend on which other features are required (e.g. hydraulic frames, impermeable floors, size and location of tanks (i.e. underground) and initial ground remediation/preparation) (EGARA, personal comm., 2014). The costs of installation, training and certification must also be considered. Finally there will be ongoing maintenance costs (EGARA, personal comm., 2014).

The main benefit of using complex depollution systems is the saving made on time and therefore labour cost from vehicle draining (EGARA, personal comm., 2014). It is possible to connect a depollution system to the vehicle, and work on other parts of the car whilst the equipment is operating automatically.

4.3.2.8 Driving force for implementation

The ELV Directive requires adequate depollution (e.g. draining of fluids such as engine oil). According to Annex I of the legislation, the minimum technical requirements for treatment in accordance with Article 6(1) and (3) are:

- Removal of batteries and liquefied gas tanks,
- Removal or neutralisation of potential explosive components, (e.g. air bags),
- Removal and separate collection and storage of fuel, motor oil, transmission oil,

- Gearbox oil, hydraulic oil, cooling liquids, antifreeze, brake fluids, air-conditioning,
- System fluids and any other fluid contained in the end-of-life vehicle, unless they are necessary for the re-use of the parts concerned,
- Removal, as far as feasible, of all components identified as containing mercury.

From July 2010, the minimum requirement for staff handling air conditioning systems must fulfil the European Union F-Gas Regulation 842/2006/EC.

Furthermore, the European Waste Catalogue and Hazardous Waste List form the basis for all national and international waste reporting obligations, such as those associated with waste licenses and permits, and the transport of waste.

4.3.2.9 Reference organisations

N/A

4.3.2.10 Reference literature

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4.3.3 General best practices for plastic and composite parts

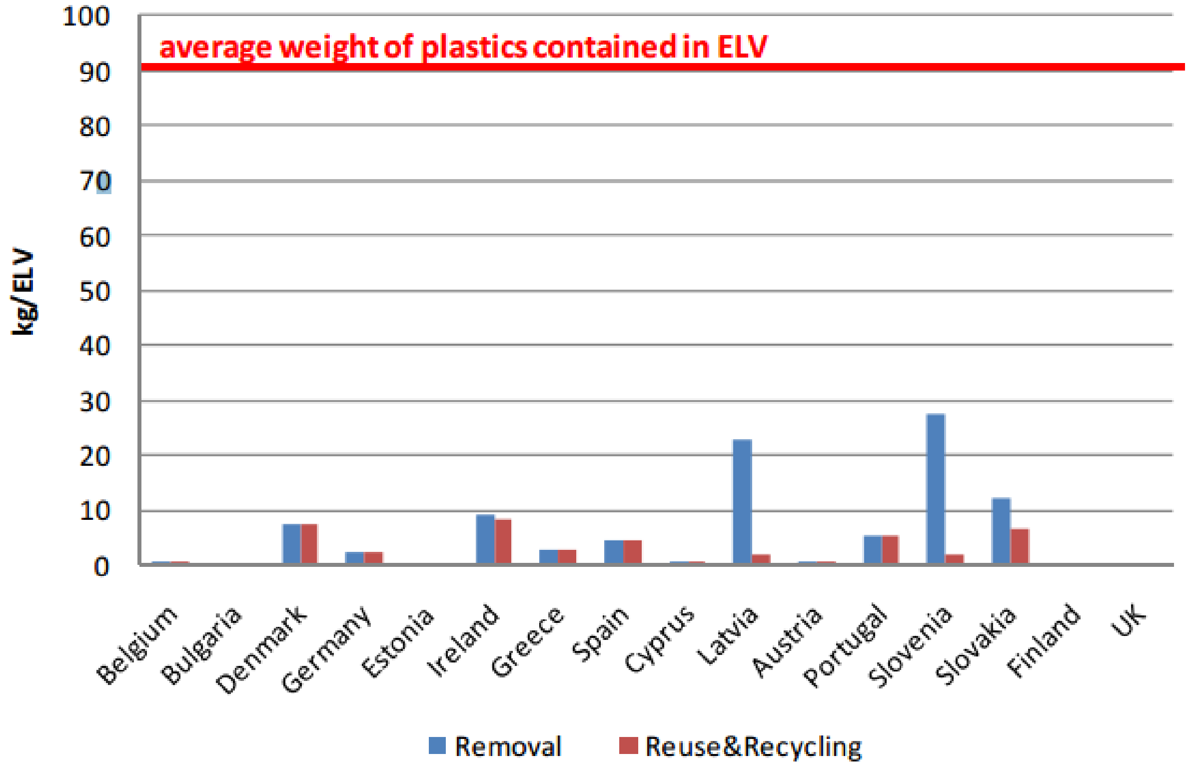
SUMMARY OVERVIEW:				
There are two main methods for treating plastic and composite parts – dismantling and recycling of components, and post-shredder recycling. The relative advantages and disadvantages of these methods depend largely on the availability and performance of ELV treatment technologies – best practice is therefore to evaluate the pros and cons based on specific information relevant to plastic and composite parts. Best practice organisations have established closed loop recycling for selected components, and continue to develop new areas to increase the level of recyclability of their vehicles.				
Relevant lifecycle stages				
Management	**Design**	**Supply chain**	**Manufacturing**	**End-of-life**
Main environmental benefits				
Energy consumption	**Resource use and waste**	**Water use & consumption**	**Emissions to air, water, soil**	Ecosystems & biodiversity
Environmental indicators				
• Conducting LCA studies to determine optimal LCA routes according to local factors (%) • Components treated according to optimal LCA route (%) • Incorporation of recycled materials into new vehicles (% weight).				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Design for sustainability using Life Cycle Assessment			
Related BEMPS	• Design for dismantling; • ELV logistics and operations			

4.3.3.1 *Description*

The average weight of plastic components in a vehicle is estimated to be around 90kg, with newer vehicles containing a higher proportion of plastic (Zero Waste Scotland, 2012). Many different polymers are used in cars – although polypropylene (PP) has the greatest share of around 40% in current ELVs (European Commission, 2007). Plastics have major applications in vehicles, including bumpers fuel tanks, body panels, battery housings, dashboards etc. The use of composite materials (such as carbon-fibre composites, polymer matrix composites etc.) is also growing very rapidly, for example in the construction of body interiors, chassis, bonnets and electrical components (Yang et al, 2012)

Annex 1 of the End-of-Life Vehicle Directive requires that large plastic components (including the bumper, dashboard, fluid containers, etc.), should be removed during the vehicle dismantling or shredding stage *if* these materials are not segregated in the shredding process in such a way that they can be effectively recycled as materials. However, compliance with these mandatory requirements appears to be poor. Monitoring data suggests that the amount of plastic removed from ELVs in Europe, prior to shredding, is small relative to the amount contained within the vehicle – see Figure 4-5.Typically plastic is left on the vehicle when it is sent for shredding, and processed into automobile shredder residue (ASR). The plastic fraction of the ASR is generally not recycled, but is more likely to be landfilled or incinerated to recover thermal energy (Schneider et al, 2010).

Figure 4-5: Weight of plastics removed from ELVs for reuse and recycling at ELV stage across Member States



Source: (Schneider et al, 2010)

Recycling of plastics and composites is particularly challenging due to the lack of clear and developed recycling routes (logistics, infrastructure and recycling technologies) relative to other material industries, the lack of clear end products/markets for recycled materials and lower quality of the recyclates compared to virgin materials (Yang et al, 2012), (Optimat, 2013). Yet the current waste management and environmental legislation in Europe increasingly requires these materials to be properly recovered and recycled from ELVs.

Long-term technology developments are still needed to optimise recycling of these materials; however there are still several key opportunities to realise best practice:

1. **Applying the principles of life cycle analysis (specific considerations);**
2. **Improving separation**
3. **Developing markets for recyclates**

Step 1) Applying the principles of life cycle analysis (specific considerations)

In general, plastics and composite materials are thought to have the most favourable environmental impacts where they allow for reduction of vehicle weight through direct substitution for other heavier materials or through parts consolidation.

There are often trade-offs with respect to different environmental aspects, and in all cases a LCA approach is recommended. Several important parameters that determine the outcomes of a LCA for plastic components should be considered in particular detail:

- **Inclusion of the whole life cycle:** it is typically the use-phase of plastic parts in cars that has the largest contribution to the environmental impacts; hence it is important not to optimise the part only for the end-of-life phase;
- **Assumptions on substitution factors:** the quality of the recycled material must be considered, as well as the application for which it will be used. For example, if the recycled plastic has inferior technical properties it may require additional material to achieve equivalent performance of the original part (depending on the application). The quality of the material

may also be affected by the recycling technology – recent developments have resulted in higher quality recyclates that are indistinguishable from virgin materials (for example see Mazda's closed-loop recycling of bumpers - Operational data).

- **Using up-to-date information on recycling processes and technologies:** To date it has often been the case that separation of plastic parts (particularly large, mono-material parts such as bumpers) before the shredder with subsequent mechanical recycling is the most preferred option, as this allows for higher-quality recycled materials to be produced. More recently, there has been significant investment in post-shredder technologies and in some cases (potentially increasingly over time) these may be preferable to pre-shredder separation. Thus the availability and performance of these technologies should be considered.

Aside from these specific considerations, the general principles outlined in *Section 3.3.2:* on *Design for sustainability using Life Cycle Analysis (LCA)* and *Section 5.1.1 on Material selection with end-of-life considerations* continue to apply. In particular, product design is a key aspect in determining the opportunities for obtaining easily separable and recyclable polymers. For example, to facilitate recycling of plastic parts, vehicle design is increasingly moving towards use of fewer polymers in vehicles, lower use of PVC, greater use of PP and avoiding composite parts of incompatible materials (European Commission, 2007). Since traditional glass, talc or mica fillers used as reinforcements can hamper recycling and cause a loss in mechanical properties over time, there is growing interest in all-PP composites that use PP polymers filled with PP fibres (Delagando et al, 2007).

Step 2) Improving separation

There are many options for end-of-life treatment, ranging from reuse of parts, separation for mechanical recycling and post-shredder treatment. The separation of different materials is important to ensure high-quality recyclates. For example, recycled plastics mixes containing many different polymers have few uses since their physical properties are very rarely suitable for replacement of virgin plastic material for any application (European Commission, 2007).

The potential for these different options depends on the separation processes employed and the material/components involved. An overview is provided in Table 4-3

Table 4-3: Overview of options for separation at different stages of ELV treatment

Option	Description
Reuse / remanufacturing	There are options to reuse and remanufacture plastic components, for example, a plastic wheel arch could be reused (as it is not safety critical) (Optimat, 2013). In practice, direct reuse may be limited by lack of standardisation in designs, problems associated with removing fixtures and damage sustained during the use phase. In some cases, repairs may be possible depending on the damage they have received. For example, holes and cracks in bumpers can be mended using a hot air plastic welder. The Urethane Supply Company provide information on how to identify the type of plastic used in the bumper (listed by make and model), as well as the method required to repair the part: • Identify the plastic - http://www.urethanesupply.com/bumperidstart.php • Identify the method and tools for repair http://www.urethanesupply.com/identify.php
Dismantling and separation before shredder	Dismantling and subsequent material recycling of plastics currently takes place at a very minor scale in Europe (Schneider et al, 2010). However, plastics removal for recycling is technically feasible and there are markets for segregated materials such as bumpers and fascia plastics – estimated at £60/tonne (€75/tonne) for baled material in 2013 (Optimat, 2013). Where waste plastics are mostly free of impurities, the recycling process itself can be relatively simple (European Commission, 2007). However, there is little incentive to segregate plastics when the scrap ELV hulk value is above the price available for individual products. Furthermore, developments of post-shredder technologies may make this option less important in future (see below).

Option	Description
Dismantling and separation post-shredder	There are some promising examples of post-shredder technologies that are able to produce high quality recyclates – for instance, in the Netherlands one ASR processing plant can produce a plastics pre-concentrate consisting of polypropylene, polyethylene, ABS and polystyrene a mixture that is processed by the company Galloo Plastics and returned in a closed-loop to automotive applications (Optimat, 2013). However, technological processes and the possibilities for recycling are different for different polymers and composite materials. The development of technology to improve separation and recycling of plastics and composites from shredder residue is essential, but proven technologies are not yet available in all Member States (Optimat, 2013).

In summary: the quality of plastic removed from ELVs at the dismantler stage is currently thought to be much higher than that recovered from ASR (which will be contaminated and a mix of polymer types) (Optimat, 2013). However, advances in technology now allow certain plastic pieces to be separated from shredder residue and thus the optimal solution may change as this technology becomes available. For example, although the Netherlands is known to remove bumpers and other large plastic parts, this practice may not continue in the future when more efficient post-shredder recovery is available (Optimat, 2013).

Step 3) Develop markets for recyclates

Vehicle and component designers are increasingly specifying plastic parts with a recycled content, which helps to stimulate a market for recycled plastics and thereby helps to improve the recycling rate for plastics in ELVs (National Composites Network, 2006).

Closed-loop recycling – often seen as the gold standard in resource efficiency – is not easy for vehicle applications - the materials used in ELVs typically date from around 12-15 years ago, and significant changes have occurred since then (European Commission, 2007). For many components, very precise properties are needed. Thus, the recycled material would not necessarily be suitable for use in the same part in a new vehicle (European Commission, 2007).

Nevertheless there are many examples of recyclates being used in vehicle components where less specific properties are required, and thus there is more flexibility in the composition of the plastic used (see Nissan Leaf case study in Section *4.3.3.5* on Operational data). This is typically in parts that are not seen by the car-user (European Commission, 2007); however, best practice methods are emerging that also incorporate plastic recyclates in visible parts.

While closed loop recycling of all of the ELV materials is unlikely to be feasible, demand exists for any recyclates that can be used to substitute for virgin materials at cheaper cost while still meeting technical specifications (European Commission, 2007). Thus the previous steps of ensuring good design and separation are important to enable plastic and composite materials recovered from ELVs to be used in different markets.

4.3.3.2 Achieved environmental benefits

The relative environmental impacts of plastics recovery largely depend on various factors such as the recovery method used and the type of substituted resources (European Commission, 2007).

Significant environmental benefits are generally expected from the recycling of individual (pure) polymers (Oko-Institut, 2003). However, numerous studies on the treatment of ELV plastics taken as a mixed whole indicate that the benefits of plastics recycling as compared to recovery are not always environmentally clear (European Commission, 2007).

As an example, the impacts of recycling bumpers are outlined below. On balance, significant environmental benefits are expected in terms of reducing energy consumption and GHG emissions compared to the current practice of landfill. Some trade-offs are also apparent in other areas – see cross-media effects for further information.

Table 4-4: Overview of environmental impacts of recycling PP/EPD bumpers compared to landfill

Recycling	Benefit / Harm per tonne	Unit
Energy consumption	5,680	MJ
Greenhouse gas emissions	992,000	gCO_2 equivalent
Air acidification	1,710	gSO_2 equivalent
Photochemical	720	G ethylene
Water pollution	(20)	m^3
Eutrophication	780	gPO_4 equivalent
Municipal waste	(20)	kg
Hazardous waste	8	kg

Source: (European Commission, 2007).

4.3.3.3 Environmental indicators

The level of implementation for each stage can be measured by:

- Conducting LCA studies to determine optimal LCA routes according to local factors (%)
- Components treated according to optimal LCA route (%)
- Incorporation of recycled materials into new vehicles (% weight).

4.3.3.4 Cross-media effects

Depending on the specific material, separation processes and recyclate markets, the environmental impacts can differ substantially. An LCA would be required to establish specific cross-media effects.

As an example, if polyurethane foam (PUF) is recycled and used again in closed loops, the physical properties can affect the environmental outcomes:

- In auto seats, the physical properties of the recycled PUF are not as good as those of the virgin material. Therefore, an extra amount of PUF must be used to provide the required performance of the seat. For example, to make one seat cushion from PU, 1.5 times the amount of recycled PU must be used compared to virgin material, which means that the use of the recycled PU will cause negative environmental impacts compared to the use of virgin material. (European Commission, 2007).
- In auto carpet underlay, the physical properties of recycled PUF are more similar to the virgin material and it can replaced an equal amount of virgin PU – this application brings environmental benefits (European Commission, 2007).

A problem common to all large plastic parts is that storage can require a lot of space, and it may be necessary for the ATF to reduce their size using energy intensive processes such as shredding. If the parts are not shredded then there will likely be large amounts of unused space in the vehicles transporting the material (MVDA - personal comm., 2014).

4.3.3.5 Operational data

Operational data in this section is based on examples which demonstrate the successful application of the steps outlined above.

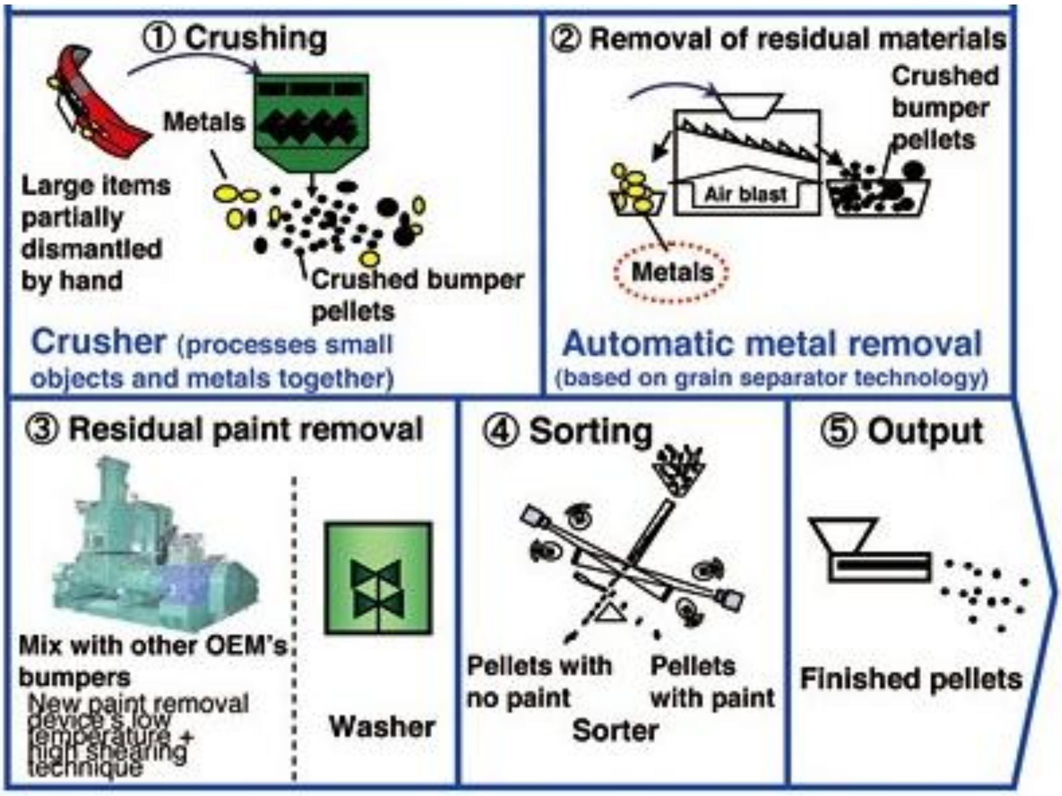
Case study 1: Mazda – automated recycling for end-of-life vehicle bumpers

Bumpers are a particularly interesting case study as they are the largest plastic component on a car and dismantling them is usually relatively easy – it has been common practice for dismantlers to remove bumpers when they block access to other parts, however they are rarely sent for recycling (Maudet and Bertoluci, 2007).

Using materials recycled from ELV bumpers is more technically challenging compared to reuse of damaged bumpers from newer vehicles, because the ELV bumpers are much older and vary in terms of their plastic composition, paint adhesive properties and use of metallic fastenings (Mazda, n.d.).

In Japan, Mazda developed a system to collect and recycle bumpers, achieving lower cost for the recycled material compared to using virgin material. In order to use the recycled material for new vehicle bumpers, a high degree of paint removal (99.85%) is required to ensure the recycled bumpers have the required surface quality and mechanical strength (Mazda, n.d.). An overview of the process is shown in Figure 4-6.

Figure 4-6: Overview of closed loop bumper recycling



Source: (Mazda, 2009)

In the 1990s Mazda began designing bumpers to be easily recyclable: the bumper which can be swiftly removed, in one piece, during dismantling. A thin-walled construction is used for the bumper underside fastenings, so they can be easily removed manually when it is pulled hard. Bumper apertures have been strengthened so that bumpers can be pulled off in one piece without breaking (Mazda, 2009).

Crushed bumper pellets undergo a paint stripping process - this employs a kneading machine which is similar to those used for processing foodstuffs and chemicals including rubber and plastics. The machine applies a powerful shear force to the crushed bumper pellets, effectively stripping off the paint regardless of the plastic composition or paint properties, and without having to heat the plastic (PlastEurope, 2011).

The sorting stage used optical sorting to detect pellets with residual paint so that they can be removed using an air jet (Mazda, n.d.). The process allows up to 30% recycled material to be incorporated in new bumpers (Mazda, n.d.).

Case study 2: Nissan – specifying high recycled material content

The Nissan Leaf uses recycled materials in almost every part of the car, many of which are plastics:

- Insulation layers in the floor and skin fabric of headlining are made with fibres from recycled plastic (Visser, 2011).
- Fabric for the seats and armrests is made from recycled PET bottles (Visser, 2011).
- Rear and front bumpers are made from used or damaged recycled bumpers that have undergone a paint removal and recycling process (Visser, 2011).
- Back door trim: End of life vehicles are taken apart and plastic components are recycled into Back door trim and door pockets of the LEAF
- Recycled materials are also used for the roof trim and carpeting and a number of other interior pieces such as the door panels and centre console storage cover (Nissan, 2012).

Figure 4-7: Overview of recycled materials used in the Nissan Leaf

Source: (Nissan, 2014)

Further examples from other manufacturers include:

- Renault is committed to using 50kg of recycled plastics in all new vehicles vehicle by 2015 (equal to an average 20% of the plastic content of a modern Renault), and has already started to implement this on their existing range of vehicles. The proportion of recovered plastic used in components varies from between 7% and 13% for Renault models under their “ECO_2” range (Renault Nissan, 2011).

- 100% recyclate parts are also used in vehicles, for example Ford have used 100% recyclate (from plastic bottles and other post-consumer waste) to create seat fabric in their REPREVE vehicle.
- Up to 15% recycled plastics are now incorporated into BMW vehicles across models (Zöbelein – personal comm., 2014).

4.3.3.6 Applicability

The quality of a plastic part at the end of its life will vary, which will affect its end-of-life treatment (MVDA - personal comm., 2014). In addition, before recycling plastic parts, unwanted materials such as metal attachments must be removed and the material must be sorted according to its recyclability. This may prohibit recycling where attachments are difficult to remove, and where the material is difficult to identify or consists of multiple, or rare polymers.

In the current context, it is not considered economically worthwhile for European ATFs to dismantle large plastic parts from vehicles, prior to shredding, due to factors such as logistical costs, space for storage, the variety of polymers in use, and the volume of materials required to make such an exercise profitable (ARN - personal comm., 2014).

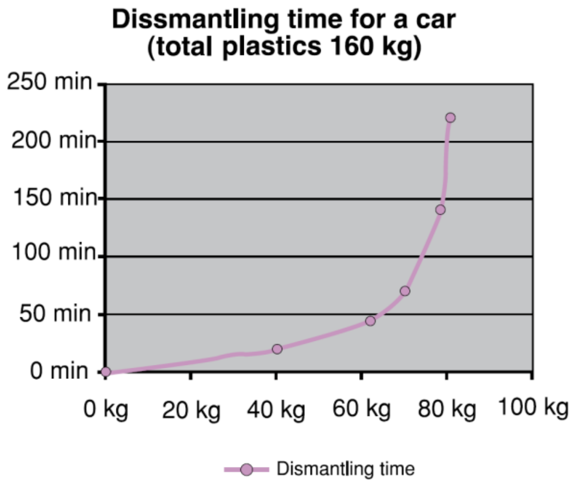
Increasing use of composites in the future will have a considerable impact on end-of-life treatment of vehicles. There is little current knowledge of how composites will be dealt with in the shredding process, which leaves questions regarding the benefits of post-shredder recovery, as well as the life cycle impact of composite materials (EGARA - personal comm., 2014), (MVDA - personal comm., 2014). Composites are usually not thermoplastics, and so cannot be recycled as granulate (ARN - personal comm., 2014). Therefore, if these plastic parts are not removed prior to shredding, then composites will become an additional contaminating element in the ASR (similar to PVC), as current post-shredder technology is not capable of isolating reinforced plastics (MVDA - personal comm., 2014), (ARN - personal comm., 2014). In addition, the metal fraction of the ASR will decrease in relation to the plastic fraction, which may affect the method of recovery for both materials (ARN - personal comm., 2014). In the current context, recycling of composites is limited due to the relatively small volumes of material in the vehicle fleet, issues concerning material identification, and the negligible value of recycled composite (MVDA - personal comm., 2014).Today, the application of recycled material in vehicles is usually limited to the non-visible areas, due to the quality of the surface finish. However, there are also applications where recyclates cannot be used from an engineering perspective. Typically, due to the varied content of recyclates, these materials have a wider range in properties, which can lead to process instabilities, in particular for critical parts with complex shapes, or those with thin walls (Schmidt & Gottselig, 2006). There is also the risk that the introduction of older plastic grades in new vehicles will not allow end-of-life recyclers to take advantage of state-of-the-art plastic processing technologies (Schmidt & Gottselig, 2006). Furthermore, typical plastics used by the automotive industry in the past may not be used in these applications in the future (i.e. recycling markets for these materials depend on the demand in other industries) (Schmidt & Gottselig, 2006). For example, historically bumpers were made from SMC or PC/PBT but there is little application for this material to be recycled today (Schmidt & Gottselig, 2006). Moreover, the contemporary fleet of vehicles only demand recycled plastics for niche applications; they cannot absorb the volumes put into the market in the past (Schmidt & Gottselig, 2006)

4.3.3.7 Economics

The removal of large plastic components from vehicles is sensitive to labour costs as well as the market price for recovered material (Optimat, 2013). In addition, the value of dismantled plastic will vary according to its quality and composition, and may be positive or negative. However, generally the costs of treatment of plastic are likely to be low compared to the cost of dismantling (GHK & Bio Intelligence Service, 2006).

There is a steep marginal cost curve associated with dismantling of plastic from ELVs. The first 70kg of plastic (i.e. large plastic parts) can be removed relatively cost-effectively, however there is a sharp increase in costs for the removal of smaller parts (Figure 4-8) (Optimat, 2013). Existing studies suggest dismantling costs for plastics of €200-300/tonne for dismantling of 30-40kg of plastics from each ELV, with costs rising towards €1,000/tonne for dismantling much larger quantities (e.g. 70kg) (European Commission, 2007).

Figure 4-8: Dismantling time for a car (total plastics 160kg)



Overcoming these economic barriers is a key issue, but examples of economically viable alternatives exist, particularly where parts are large and more easily removed – for instance, Mazda's advanced closed-loop recycling technique makes closed loop recycling for bumpers cheaper than the cost of new material (PlastEurope, 2011). Furthermore, one case-study, in Holland, showed that post-shredder treatment can cost as much money to run as it would cost to pay for pre-shredder dismantling (EGARA - personal comm., 2014).

The development of a market for recyclate is also a key issue which is affected by the cost of virgin material relative to recyclate. The use of recycled material in components will be heavily influenced by the distance of the manufacture site from the source of supply; as the value per kg falls for a material, so it becomes uneconomic to move it very far.

Nevertheless, post-shredder advanced mechanical separation may provide a more cost effective recycling option, although quality of the recycled material may be lower.

4.3.3.8 Driving force for implementation

Regulatory factors are a key driver. The End-of-Life Vehicle Directive (2000/53/EC) sets a target of 95% recovery by 2015 for vehicles below 3.5 tonnes, and therefore indirectly sets targets for large plastic parts. Furthermore, Annex I of the Directive specifies that certain materials must be removed from an ELV at the dismantling stage to promote recycling, including large plastic components, if these materials are not segregated in the shredding process.

There is also a competitive element to recycling: if a manufacturer can achieve closed-loop recycling then they stand to save money on virgin polymers used in the production process.

4.3.3.9 Reference organisations

The Japanese unit of Mazda has tested and achieved implementation of some of the recommendations relating to simplification of large plastic part design, removal and closed-loop recycling.

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4.3.4 Wiring harnesses – best practice for ELV treatment

SUMMARY OVERVIEW:				
Frontrunner organisations have implemented closed loop recycling for vehicle wiring harnesses through combining design factors, dismantling tools and recycling processes				
Relevant lifecycle stages				
Management	**Design**	Supply chain	Manufacturing	**End-of-life**
Main environmental benefits				
Energy consumption	**Resource use and waste**	Water use & consumption	Emissions to air, water, soil	Ecosystems & biodiversity
Environmental indicators				
• Recycling rate (%) • Reduction in environmental impacts according to LCA criteria				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Design for sustainability using Life Cycle Assessment			
Related BEMPS	• Design for dismantling; • ELV logistics and operations			

4.3.4.1 *Description*

Metal recycling is a mature process, and the majority of copper contained within a vehicle is usually recovered and recycled effectively during post-shredder treatment. However, the copper in a vehicle wiring harness can present a problem for separation, since light fraction fibres may attach to wires. Therefore it is possible that a significant fraction of copper from wire harnesses may not be separated in the shredder and could end up in landfill (Brahmst, 2006).

The conventional wiring harness of a vehicle is a complex arrangement of electrical cables, plugs connectors etc. that delivers electrical power and communications. There has been a significant shift in the proportion of electronics in the average vehicle in recent years. This has been fuelled by new products to control the vehicle such as engine, transmission, braking systems, on-board infotainment etc. As more electronics are added to the vehicle the wiring harness has increased in weight and therefore also in importance with respect to reuse, recovery and recycling targets (Optimat, 2013).

Best practice for the end-of-life treatment of wiring harnesses for current vehicles focuses on improving the removal and recycling rates as far as possible. Earlier intervention at the design stage can have also a substantial impact on the feasibility of subsequent stages. Figure 4-9 illustrates the main options, ordered from intervention at an earlier stage to the later stages.

Figure 4-9: General hierarchy of wiring harness options

Early intervention ↓ Cumulative benefits	Options	
	(1) Intervention at design stage	Improved design for dismantling
		Simplifying CAN bus
	(2) Improving dismantling rates	Improved dismantling tools
		Improved dismantling practices
	(3) Improving recycling processes	Pre-shredder recycling
		Recycling of materials

Note that the guidance in this section focusses on recovering the copper in the wiring harness, as it presents an issue specific to the automotive sector. More general guidance on best practices for electronics can be found in the Sectoral Reference Document providing **Best Environmental Practices for Electronics and Electrical Components** (forthcoming).

Option 1: Intervention at design stage

General principles for improving the ease of dismantling were outlined in *Section 5.1.2: Design for dismantling*. However, there are some additional specific actions that can be beneficial for the design of the wiring harness:

- Adapting the routing of the wiring harness through the vehicle can make it more accessible to a dismantler (Brahmst, 2006);
- Alternative connections to the body of the vehicle can make it more easily detachable (Brahmst, 2006);
- Reducing the weight of the harness by replacing copper with aluminium, and the use of plastic fibre-optic cable (Optimat, 2013) (Laser Focus World, 2012).

Option 2: Improved dismantling rates

Current ELVs clearly cannot benefit from the design interventions described in Option 1, and therefore improved dismantling approaches are needed to deal with conventional harness designs.

Wiring harnesses are typically labour-intensive (and therefore expensive) to remove. In addition, they are typically not interchangeable with harnesses in other vehicles – there are wide variations in the layout between models (and even within the same model range) as well as the connectors, terminals and wire standards (Pradham, 2011). As a result, the harness will often remain in the vehicle when it is sent for shredding (Brahmst, 2006). This is undesirable since it can reduce the achievable recycling levels.

In Japan, dismantling technology appears to be more advanced due to the requirements of the Japanese ELV legislation, where dismantlers are required to remove wiring harnesses (Optimat, 2013). This is typically done using heavy machinery such as JCB rippers.

However, even simple methods can result in improvements in the time take to dismantle wiring harnesses:

- By cutting the cables instead of unplugging the plugs, the dismantling times could be decreased by 30% (SEES, 2005);
- Dismantling times can also be decreased by using new cutting tools (SEES, 2005). To most efficiently remove the wiring harness, dismantlers should use new cable cutters.

Option 3: Improved recycling practices

High levels of customisation and differing wiring needs for the engine control system, as well as the complexity of the harness, mean that reuse of dismantled harnesses is very limited, if possible at all (Brahmst, 2006). The best alternative is therefore to improve recycling practices by ensuring that wiring harnesses are processed separately where possible.

When wiring harnesses are removed using conventional manual methods, it is extremely difficult to separate the copper from the fuse box and other components due to the complex structure. As a result, it has not been possible to recycle harnesses using mechanical sorting methods. The wire harness has a comparatively large insulation relative to its copper content, so it is highly likely that most of the shredded wire harness becomes part of the shredder residue (Brahmst, 2006).

Closed loop recycling, where the materials from recovered harnesses are recycled into new, is considered best practice. Copper in pre-shredded wiring harnesses can be recovered and recycled to a purity level of 99.96% from the wiring found in automobiles (Recycling Today, 2014).

4.3.4.2 Achieved environmental benefits

Higher levels of dismantling could contribute to greater levels of material recovery - interviews with shredder companies suggest that if wiring harnesses were able to be removed and processed separately, virtually all of the copper could be recovered (Brahmst, 2006). Currently, the vehicle wiring harness for a mid-range car can weigh around 20kg, and double or triple this for a luxury vehicle (Optimat, 2013).

Toyota started a new copper recycling project in 2013, and to date around 200,000 Toyota vehicles have used recycled copper for part of their wire harnesses (Recycling Today, 2014). Trial production involving small amounts of recycled copper began at TMC's Honsha, Japan, plant in 2013. The copper has since been introduced to the wiring harness manufacturing line and stable production involving recycled copper has been achieved. Toyota estimates as much as 1,000 tonnes of copper can be produced annually using the new process (Recycling Today, 2014).

4.3.4.3 Environmental indicators

The environmental benefits of design changes and greater opportunities for dismantling are not directly quantifiable, but monitoring can be established in terms of the average time take to disassemble the harness, as well as the penetration of such designs in the model range.

In terms of improving the recycling practices, recommended indicators are:

- Recycling rate (%)
  Reduction in environmental impacts according to LCA criteria (see *Section 3.3.2:* on *Design for sustainability using Life Cycle Analysis (LCA)).*

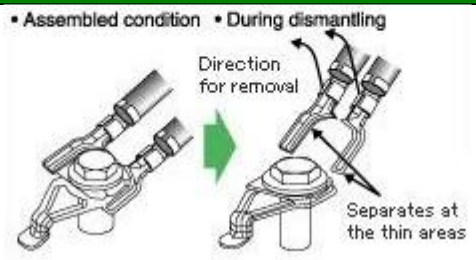
4.3.4.4 Cross-media effects

Overall there are not expected to be any significant environmental trade-offs, particularly where wiring harnesses are diverted from landfill to recycling operations.

4.3.4.5 Operational data

Operational data in this section is based on a case study from Toyota, who have successfully implemented all three best practice steps outlined above. Details are summarised in Table 4-5.

Table 4-5: Toyota case study

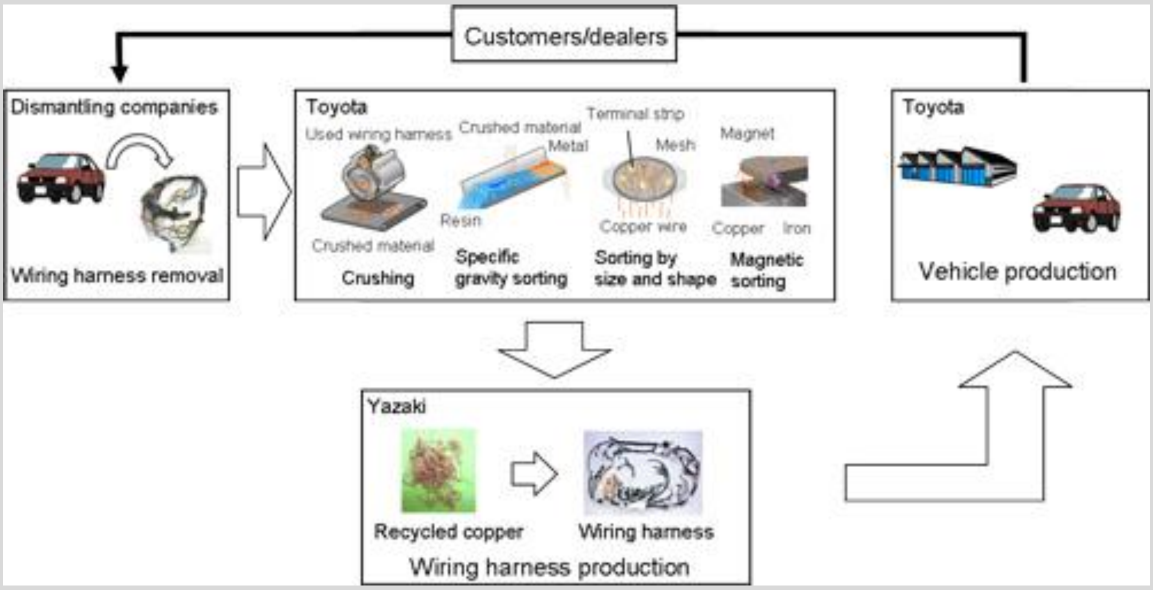
(1) Intervention at design stage	
A structure has been designed that allows the wiring harness to come apart like a pull-tab at the grounding terminal when the wiring harness is pulled hard for removal	
The wiring harness is laid out above the instrument panel reinforcement, so there is no need to contact other parts when removing it	

(2) Improving dismantling

In order to improve the ability for dismantlers to remove the wiring harness in one piece, Toyota began to evaluate the potential for dismantling at the design stage. Heavy machinery is widely used by dismantlers for removing parts such as wiring harnesses (Toyota, 2013)

(3) Improving reuse and recycling rates

Toyota with a number of partner firms in Japan have developed a technology to recycle the copper in wiring harnesses, producing a copper with a purity level of 99.96% (Recycling Today, 2014). The process involves crushing a vehicle's wiring assembly and sorting the copper from other materials by examining differences in buoyancy (e.g. resin) and using magnets (for iron).



Source: (Toyota, 2013), (ATF Professional, 2014), (Recycling Today, 2014)

4.3.4.6 Applicability

Reuse of wiring harnesses has historically not been widely practiced due to the difficulty in identifying whether a wiring harness can be used interchangeably with other vehicles; even within models customisation options result in a wide variety of wiring harness designs (Brahmst, 2006). According to Fiat, several OEMs have investigated the potential for removing wiring harnesses and concluded that the processes are too labour intensive compared to the gain in terms of material, although they recognise that other carmakers have developed methods to remove the wiring harness without interfering with other components (Fiat - personal comm., 2014).

However, pre-shredder recycling is viable if the cost of removal from the body is low enough, and according to Toyota, the copper in wiring harnesses can be recycled to a purity sufficient for use in the manufacture of new wiring harnesses (Recycling Today, 2014).

The use of heavy machinery to remove wiring harnesses is currently limited in the European market. This is thought to be because the financial incentive for ATFs to dismantle an ELV resides in the spare parts that can be recuperated for reuse (ARN - personal comm., 2014).

4.3.4.7 Economics

Currently in Europe, there are some ATFs that remove copper wiring and sell it to copper scrap dealers (ARN - personal comm., 2014). However, this practice depends on the labour costs involved; if an ATF experiences a period in which they receive fewer ELVs, then they will have an abundant labour force which can be applied to removing more materials and components from a vehicle (EGARA - personal comm., 2014). However, labour costs in Western Europe are such that this is unlikely to be a sustainable practice in all Member States (ARN - personal comm., 2014).

From the OEM’s perspective, closed-loop recycling can help to circumvent the global material market by ensuring the product returns to the original manufacturer, thereby ensuring security of supply. Toyota have cited their copper recycling process as a new source of competitiveness as they combat resource depletion (Recycling Today, 2014).

Where manufacturers do not reclaim the harness, decisions are based on whether removal and recycling are economical given the prevailing scrap prices. Dismantling times for wire harnesses can range from 5 minutes to over 30 minutes, depending on the accessibility and complexity – with newer cars tending to have much higher times/costs (SEES, 2005) – therefore easier dismantling is likely to improve the economic viability of this option.

The Recycling and Dismantling Centre of the BMW Group (RDZ), Munich, use a purpose-built heavy machine called the ‘Excavator’. The Excavator was developed specifically for BMW use, but will soon be commercially available to other firms. It is most useful for removal of wiring harnesses (as well as aluminium body parts and the catalytic converter) (Zöbelein, 2014). Concerning the wiring harnesses, cost savings are made through reduction in labour time (an estimated 6 hours manual labour is reduced to 3-5 minutes using the Excavator), increased revenue from the sale of harnesses to recyclers (estimated average harness price of €60-€100, with and 70-90% recovery rates using the excavator), increase in sale price of baled hulks for shredding due to reduced copper and PVC content (€5-€10) (Zöbelein, 2014).

4.3.4.8 Driving force for implementation

ATFs will primarily be driven to remove a vehicle part if it is financially worthwhile to do so (ARN - personal comm., 2014); copper is increasingly removed due to its increasing price (EGARA - personal comm., 2014). However, currently the primary driver for removing the wiring harness pre-shredder is to increase the value of the ASR (MVDA - personal comm., 2014).

Regulatory factors are a key driver, in particular:

- The End-of-Life Vehicle Directive (2000/53/EC) sets a target of 95% recovery by 2015 for vehicles below 3.5 tonnes, and therefore indirectly sets targets for wiring harnesses;
- Japanese ELV legislation contains provisions for 'Whole Vehicle Utilisation', which requires dismantlers to reduce copper contents in vehicles to not more than 0.3%. This requires the removal of wiring harnesses (Optimat, 2013).

Concern over future availability of copper is also of increasing importance. It is estimated that only 40 years of mineable copper resources remain worldwide, while global consumption continues to grow. In particular to the automotive sector, significant quantities of copper are used in the motors of hybrid vehicles (ATF Professional, 2014).

4.3.4.9 Reference organisations

The European units of Ford and Volkswagen have tested and achieved implementation of some of the recommendations relating to simplification of wiring harness design and removal (Brahmst, 2006).

4.3.4.10 Reference literature

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4.3.5 Glazing – best practice for ELV treatment

SUMMARY OVERVIEW:				
In cases where life cycle assessment indicates that dismantling automotive glass prior to shredding is more environmentally beneficial, frontrunner organisations facilitate this process through the ELV network in an economically viable manner. This requires efficient removal of glass, separate treatment and recycling into high quality products				
Relevant lifecycle stages				
Management	Design	Supply chain	Manufacturing	**End-of-life**
Main environmental benefits				
Energy consumption	**Resource use and waste**	Water use & consumption	Emissions to air, water, soil	Ecosystems & biodiversity
Environmental indicators				
• Recycling rate (%) • Reduction in environmental impacts according to LCA criteria				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Design for sustainability using Life Cycle Assessment			
Related BEMPS	• Design for dismantling • ELV logistics and operations			

4.3.5.1 Description

The weight of glazing within a vehicle makes its recovery an important aspect for meeting recycling targets required under the End-of-Life Vehicle (ELV) Directive (2000/53/EC). Furthermore, by 2015 the removal and treatment of glazing will be required by Annex I of ELV Directive.

Manual removal of automotive glazing is labour intensive and therefore expensive, while the reuse and recycling options are limited – as such, many ELVs in Europe are shredded with the glazing still in place (Glass for Europe, 2009). Shredded glass will often be mixed with other residuals and contaminated with organic substances, resulting in almost no market value – as a result it may be sent to landfill (Farel, et al., 2013).

Life-cycle assessments of treatment options suggest that **dismantling the glass from an ELV prior to shredding** represents the best environmental practice (Lassesson, 2008), (Manshoven, et al., 2013). If glazing is effectively and efficiently removed from an ELV prior to shredding, there are established processes to recycle the glass.

Hence, it is possible to dismantle the glass from an ELV, collect and transport the glass to treatment units, purify the glass and obtain clean and reusable glass raw material called cullet (Farel, et al., 2013).

The recyclable quantities of glass in ELVs depend on the care taken to dismantle the glass, therefore best practice is to dismantle the windows leaving as much intact as possible:

- Where glazing is fixed using rubber seals, the entire window can easily be removed (GHK & Bio Intelligence Service, 2006).
- If the window is fixed in place by direct bonding, the most effective method of removal is to cut out as much as possible from the centre of the window, leaving glass in place around the edges (GHK & Bio Intelligence Service, 2006). For example, the centre of a windshield can be cut out using a diamond wheel cutter or chisel, but this method leaves the edges of the window (15-25% of the glass) in place (Saint-Gobain Sekurit, 2014).

Finally, for best practice, windshields should not be mixed with side windows, as only windshields require laminated glass treatment, which is more costly. Mixing two inventories decreases quality and

may lead to extra costs. The dismantled glazing must also be stored in special boxes to prevent pollution (Farel et al, 2013).

4.3.5.2 Achieved environmental benefits

Automotive glazing accounts for around 3% of an ELV by weight (Glass for Europe, 2009), and is expected to increase by 5-10% in the future, according to the current trend of increasing vehicle glazing surfaces (Farel, et al., 2013).

Cullet is commonly used for making glass products, glass wool, or as a substitution for other raw materials. This is because each 10% increase in cullet used in a glass furnace results in a 2-3% energy saving in the melting process: and each tonne of cullet used saves 230 kg of CO_2 emissions (Farel, et al., 2013). The glass production industry uses cullet for two main reasons: it is relatively less expensive than raw material (Silica) and consumes less electrical energy in the furnaces for melting (Farel et al, 2013).

4.3.5.3 Environmental indicators

In terms of improving the recycling practices, recommended indicators are:

- Recycling rate (%)
- Reduction in environmental impacts according to LCA criteria (see *Section 3.3.2: Design for sustainability using Life Cycle Analysis (LCA)).*

4.3.5.4 Cross-media effects

Overall there are not expected to be any significant environmental trade-offs, particularly where glazing is diverted from landfill to recycling operations.

4.3.5.5 Operational data

Laminated glass (as used in windshields) can be time consuming to remove, and locking mechanisms can also cause problems when removing glass from doors (GHK & Bio Intelligence Service, 2006). Due to the high labour costs in developed countries, the manual recovery of ELV glazing can be very costly and can amount to several hundred Euros per ton of recovered glass (Saint-Gobain Sekurit, 2014). However there are tools which can facilitate the process, saving cost and increasing the incentive for dismantlers to remove the part (Farel, et al., 2013).

In the Netherlands, where removal and recycling of automotive glazing has been common, an ATF expert advised that windscreen glass was removed most effectively by driving the forks of a forklift truck into the windscreen and lifting it out (EGARA - personal comm., 2014). The technique is rapid and highly effective at capturing the majority of material from the windscreen. In contrast, the side windows, were commonly removed by shattering glass into a curtain which catches the majority of pieces. In the Dutch context, cutting the window out using cutting tools took too much time, and was therefore prohibitively expensive (EGARA - personal comm., 2014).To achieve effective recycling of automotive glazing requires collaboration throughout a network of stakeholders, including car manufacturers, ELV dismantlers and shredders, collection and transportation companies, and glass treatment facilities (Farel, et al., 2013). For example, in Italy, Fiat has developed a network of 300 approved agents, who are trained in dismantling and separating reusable components, including glass, for recycling (FIAT, n.d.). However, Italy is unusual in having high and unsatisfied demand for cullet, which is generally recycled into wine bottles, making the recycling of glass economically viable (Australian Government; Department of Environment, 2002).

4.3.5.6 Applicability

The direct reuse of glazing from ELVs is usually not possible, due to an inability to dismantle the part without compromising its integrity (Saint-Gobain Sekurit, 2014); particularly in modern cars where the fixed glazing is sometimes bonded to the body (Glass for Europe, 2009).

A typical European car contains four types of glazing: windshield, fixed side windows, mobile side windows, and back windows, each associated with different material concentration ranges. The glazing in a contemporary passenger car comprises a windshield containing layers of polyvinyl butyral (PVB) (~17kg) and a back window containing metal wire (~15kg) (Farel, et al., 2013). Other materials commonly found within the glazing include plastic interlayers, ceramic inks, silver printing electrical connectors, encapsulation materials, fixing clips (Glass for Europe, 2009). Despite the additional materials present in the ELV glazing, the recycling yield is typically over 99% when recycled in a single waste stream (Farel et al, 2013).

However, a comprehensive comparison of the environmental benefits of available options should be made before the method of treatment is decided. In the Netherlands, the resultant cullet was typically used in the production of glass wool which is an energy intensive process. If the CO_2 emissions from glass wool production are compared with any other application of a mineral fraction containing glass, then the mineral fraction will typically have a lower carbon footprint (ARN - personal comm., 2014).

Removal rates will also be affected by whether an ATF specialises in a certain type of vehicle. If an ATF specialises in larger vehicles then they can expect to retrieve a more significant volume of glass per vehicle, for the same amount of labour. Whereas if they specialise in smaller vehicles the quantities of material to remove are more limited (EGARA - personal comm., 2014). This will influence their consideration of whether it is economically worthwhile to remove the material.

The PVB layer within a windshield (10% by weight) can be recycled or recovered through incineration (Saint-Gobain Sekurit, 2014), if the windshield is removed prior to shredding. The PVB layer can be separated by crushing the part into small pieces (3-5mm) through two consecutive stages of shredding (Saint-Gobain Sekurit, 2014).

4.3.5.7 Economics

To achieve effective recycling of automotive glazing requires collaboration throughout a network of stakeholders, including car manufacturers, ELV dismantlers and shredders, collection and transportation companies, and glass treatment facilities (Farel, et al., 2013).

Table 4-6 shows the estimated costs and income for different actors in the ELV glazing recycling network. It can be seen that the economic viability depends on the cullet price, landfill cost, and the penalty associated with failing to comply with the ELV Directive (2000/53/EC) (Farel, et al., 2013). Good quality cullet that can be used for glass production has the highest price, close to the raw material price (Farel, et al., 2013). However, in Europe the supply of glass cullet available from alternative consumer sources is often large and can negate the economic incentive to remove glazing from vehicles at a comparatively higher cost (ARN - personal comm., 2014).

Table 4-6: Estimation of costs and income for the ELV glazing recycling network

Operation	Cost	Income	CO_2 emissions
Dismantle and store the glazing	40-50 €/T removed glazing	10-15 €/T sale	Negligible
Transportation to treatment centre	60-85 /T glazing	-	0.04 /T glazing
Treatment of ELV glass	20-30 /T cullet (purchase + process)	40-50 €/T Sale cullet	0.0019 / T cullet
Re-melting cullet for recycling	-	2-5 €/t cullet price difference (cullet - raw material)	-0.23 /T glass
Landfill avoidance	108,4 €/T landfill cost	80 €/T Saving costs in landfill cost	Negligible

Source: (Farel et al, 2013)

The incentive for each party is also limited by the benefit they receive. Dismantlers must remove the glazing from the vehicle and sort and store it according to the proposed method of treatment (i.e. laminated, silver printed rear windows etc) (MVDA - personal comm., 2014). The average time for this

operation is estimated at five minutes per vehicle, at a cost of €4-€5 per vehicle (Glass for Europe, 2009). This process increases the time and therefore cost of the dismantling process. Furthermore, transportation of the dismantled glass to a treatment unit can often cost more than the buyer can offer (Farel, et al., 2013). Finally there are economic benefits associated with shredding the glass: the glass fraction of ASR can be used to replace raw materials in other applications (e.g. in road surfaces). On the other hand, car manufacturers can avoid the penalty associated with not meeting targets and dismantlers/shredders can avoid the cost of landfilling unusable ASR. These factors combined mean glazing is usually left in the hulk of the vehicle when it is sent for shredding.

4.3.5.8 Driving force for implementation

Table 4-7 shows the driving forces and barriers applicable to different stakeholders.

Table 4-7: Individual motivation and disincentives of stakeholders for a future ELV glazing recycling network

Stakeholder	Motivation for recycling	Disincentive for recycling
Car manufacturer	Achieve 95% ELV recycling target	None
Dismantler	Achieve a higher dismantling rate and use commercial benefits and potential government subsidies	Additional cost
Shredder	Reduce landfill cost	None
Collection and transportation	Improve logistics	Volume issues
Glass treatment	Increase feed and product flow	None
Cullet buyer	Satisfy demand	Quality issues

Source: (Farel, et al., 2013).

4.3.5.9 Reference organisations

N/A

4.3.5.10 Reference literature

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4.3.6 Tyres – best practice for ELV treatment

SUMMARY OVERVIEW:				
The best environmental management options for tyres may vary depending on local factors, but generally the best options are to recycle tyres into applications that can displace virgin materials (including closed-loop recycling into new tyres) or to use as tyre-derived fuel in cases where coal is displaced.				
Relevant lifecycle stages				
Management	Design	Supply chain	Manufacturing	**End-of-life**
Main environmental benefits				
Energy consumption	**Resource use and waste**	Water use & consumption	Emissions to air, water, soil	Ecosystems & biodiversity
Environmental indicators				
• Volume of tyres recovered and the percentage being sent to the environmentally preferred treatment method • Reduction in environmental impacts according to LCA criteria				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Design for sustainability using Life Cycle Assessment			
Related BEMPS	• Design for dismantling; • ELV logistics and operations			

4.3.6.1 Description

There are numerous possibilities for the treatment end-of-life tyres (ELTs), with differing environmental impacts. Best practices for tyres are discussed here as they do not necessarily adhere to the traditional “waste hierarchy”, which implies that end-use applications requiring the lease reprocessing should be preferred over applications that require more processing.

Tyres can be used whole as filler materials in civil works, and as cushioning element in harbours and motorsport circuits. They can also be processed for material recovery (i.e. shredding, grinding, pyrolysis) and energy recovery (i.e. cement kilns and power plants).

As a guide, Figure 4-10 shows a hierarchy of potential options according to a traditional “waste hierarchy”, ordered from the most preferable to the least preferable. The most preferable options – encouraging longer usage and direct reuse/retreading – are typically the best from an environmental perspective but are not always available. Note in particular that recycling and energy recovery options are labelled as 3.a and 3.b because the environmental impacts may differ depending on the local circumstances.

Figure 4-10: General hierarchy of ELT management options

Lower waste	Options	
↑	(1) Encourage longer usage periods	Longer-life tyres
		Better driving habits
		Better maintenance
	(2) Direct reuse and retreading	Direct reuse of part-worns
		Retreading of suitable tyres
	(3.a) Recycling and reprocessing of materials	Use of larger tyre parts/shreds
		Use of smaller tyre shreds
		Use of large granulate
		Use of small granulate
		Use of large powder
		Use of small powder
	(3.b) Energy recovery	Use of whole tyres as fuel
		Use of shredded tyres as fuel
	(4) Recycling of materials (whole)	Reuse of whole tyres in other industries
No benefit	Landfilling	Banned

Notes: Preference ordering is indicative only – depending on specific circumstances, different methods may appear in a different order and therefore LCA should be conducted.

Source: Adapted from (WRAP, 2006)

Best practice organisations should therefore consider the steps outlined in Box 4-1:

Box 4-1: Best practice steps for ELT treatment decisions

- **Assess the potential for direct reuse and retreading:** This is determined by the quality of the tyre casings, the extent of tread wear and market demand.
- **Conduct LCA to determine the best options for ELTs that cannot be directly reused or retreaded:** A life cycle assessment should be used to determine the best options, based on local circumstances, considering the range of possible end-uses.
- **Choose the optimal technology to generate rubber shreds/crumb:** based on the required size and quality that is necessary to meet the end-use (see Section 4.3.6.5 Operational data).
- **Take steps to develop markets for ELTs where they do not currently exist**: this can be a long-term activity. It is important to ensure that ELT markets are viable from a technical, economic and environmental perspective. Key factors to consider when evaluating different end-use markets include (WBCSD, 2010):
  - Whether there is existing demand for ELT-derived products;
  - Whether appropriate supply chains and infrastructure are in place;
  - Whether the market is likely to be viable in the long term (in a competitive free market without subsidies).

Further details on each of the options for ELT treatment (from Figure 4-10) are outlined below.

Option 1: Encouraging longer usage periods

Options that aim to encourage extended use periods are outside of the scope of this guidance as they generally relate to user choices, but as best practice organisations encourage these practices through informing consumers about tyre care – for example, Michelin provides user-friendly advice on their website[34] with information on how to extend the life of tyres through better maintenance and driving.

Option 2: Reuse and retreading

The second-best option to reduce waste is direct reuse or retreading of tyres.

- **Direct reuse:** It may be possible to reuse part-worn tyres directly on other vehicles, in which case tyres are mounted on the vehicle with little or no repair.
- **Retreading:** the worn part of the tyre is replaced and the tyre is brought back into the same service conditions without sacrificing performance. This option is only possible if the tyre casing (i.e. the internal structure) is in good condition when recovered (see Section 4.3.6.5 Operational data for further details).

Retreading of passenger car tyres is relatively uncommon compared to truck tyres (where the industry is mature), but should be considered where the option exists.

Option 3.a: Recycling and reprocessing of materials

Recycling of ELTs involves shredding or grinding the tyres for use in a wide variety of different applications (ETRMA, 2014):

- **Rubber shreds:** used as a foundation for roads and railways, as a draining material replacement for sand and gravels, landfill construction, subgrade fill and embankments; backfill for walls and bridges and subgrade insulation for roads. The tyre aggregate is lighter by 30-50%; drains ten times better than well graded soil and provides eight times better insulation than gravel.
- **Rubber granulates:** Applications of ELT rubber granulates include artificial turf and moulded rubber products such as wheels for caddies, dustbins, wheelbarrows and lawnmowers.

Option 3.b: Energy recovery

ELT are used as a tyre derived fuel (TDF) as part of co-processing in the cement industry, and as supplementary fuel for power generation or in waste-to-energy plants. The co-combustion of tyres in cement kilns is currently the leading thermal technology, where the main advantage of using tyres is due to their high calorific value and cheapness as a fuel, as well as the good quality of the cement obtained (Nemry, et al., 2008).

Energy recovery options are not considered in detail in this guidance – further technical details for best practices can be found in the **Reference Document on Best Available Techniques for the Waste Treatment Industries** (European Commission, 2006). Thermal treatment technologies – pyrolysis, thermolysis and gasification – are some of the emerging solutions for recovering value from end-of-life tyres.

Option 4: Material recycling (use of whole tyres)

Whole tyres are predominantly used in civil engineering applications such as coastal protection, erosion barriers, artificial reefs, breakwaters, slope stabilisation, road embankments and insulation.

According to traditional waste hierarchy approaches, applications that can utilise larger rubber pieces are generally thought to be more environmentally beneficial because less energy is required to process the rubber. In particular, the use of whole tyres is found to be less preferable compared to energy recovery methods (Aliapur, 2010).

[34] http://www.michelin.co.uk/tyres/learn-share/care-guide

4.3.6.2 Achieved environmental benefits

The main environmental benefits come from avoiding the use of virgin materials (including avoiding the production and transport of the substituted materials).

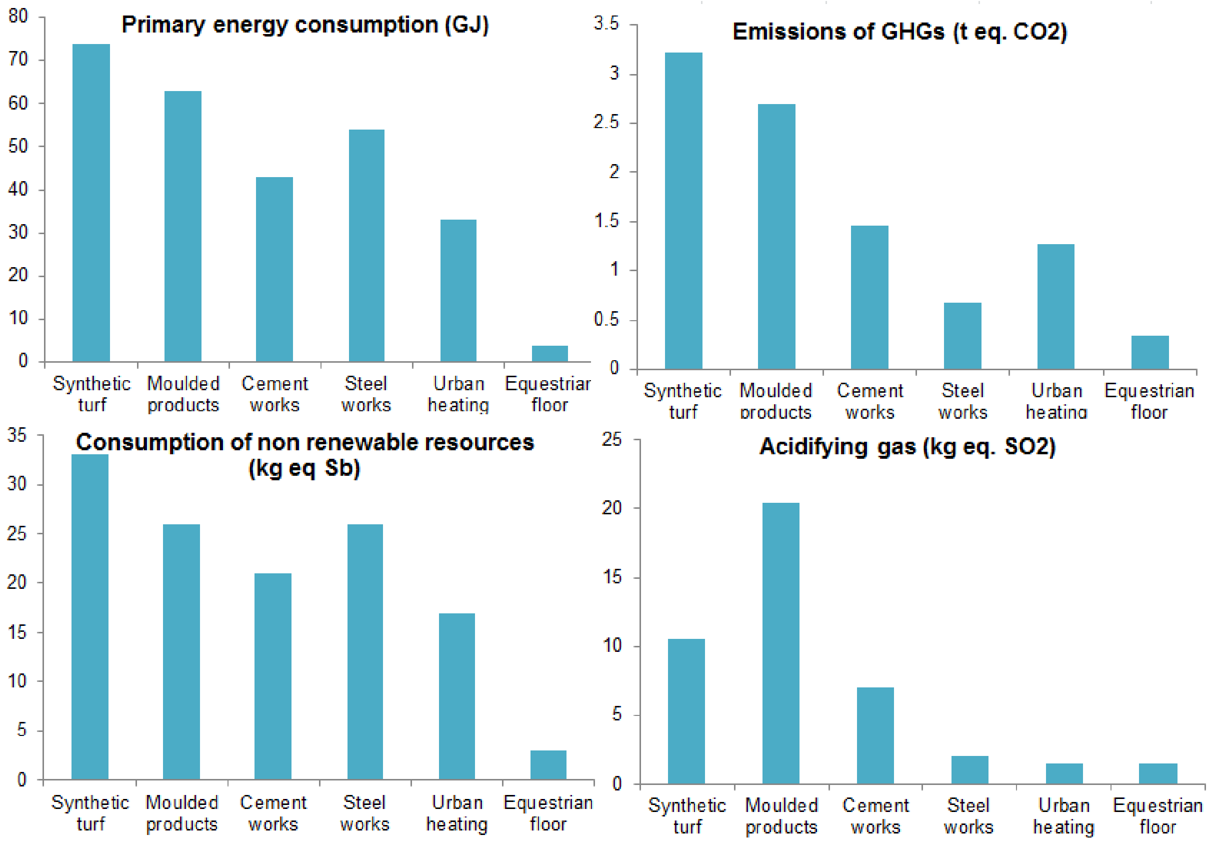
Direct reuse of tyres and retreading are typically the most preferred options from an environmental perspective (WRAP, 2009). A high quality retreaded tyre is typically comparable to a new tyre in almost all properties (safety, service life etc), with the exception of rolling resistance (Continental, 2006) – effectively doubling the life of a tyre. The amount of new material required to retread the tyre is small compared to the amount contained in the old tyre casing. Figures for the lifecycle impacts are as follows (Continental, 2006):

- Waste production: 85% reduction for a retread compared to a new tyre (over the lifecycle);
- Water consumption: 86% reduction;
- Although around 2.3 times more energy is needed to manufacture a new tyre compared to a retread, the CO_2, NOx and SO_2 reductions over the lifecycle depend on the quality of the retread and the achieved rolling resistance (higher rolling resistance leads to higher vehicle fuel consumption). For an assumed rolling resistance that is 3% higher for a retread, the impacts on CO_2, NOx and SO_2 are approximately neutral.

However, an important factor is that the above figures hold only for high quality retreads - for poor quality retreads, the environmental impacts could be completely negated and even become negative (Continental, 2006). As vehicles become more fuel-efficient and limits of tailpipe air pollutant emissions become more stringent, these trade-offs will change.

It should be noted that in the case of tyres, certain material recovery methods do not necessarily have systematically better environmental results compared to energy recovery methods (Aliapur, 2010). A comparison of the environmental benefits over the lifecycle from different ELT options is shown in Figure 4-11.

Figure 4-11: Comparison of environmental benefits over the lifecycle from selected ELT treatment methods (higher = greater benefit)



Notes: Assumes that coal is the displaced fuel from cement works

Source: Adapted from (Aliapur, 2010)

While all ELT options have benefits relative to landfilling, the magnitude of these impacts varies depending on the treatment method as well as other local factors (such as the energy generation mix).

In general, material recovery in ground rubber applications such as synthetic turf and moulded objects were found to be the most beneficial in a number of environmental categories, where recycled tyres were able to replace virgin materials. The benefits generally depend on what materials are displaced – e.g. generally, displacing products such as asphaltine and concrete are highly beneficial.

The benefits of tyre-derived fuels appear to stem largely from displacement of coal – this was the scenario modelled in Figure 4-11 (Aliapur, 2010). Therefore careful consideration of the displaced fuel is needed when studying the lifecycle impacts – for displacement of other fuels, the benefits are reduced. For example, substitution of 50/50 hard coal and lignite or of waste plastic in the incineration process would make incineration less favourable and thus material recycling may be preferable (Genan, 2009).

Reuse of whole/large tyre parts in civil engineering works were the least beneficial (e.g. retention basins and infiltration basins –not shown on the graphs above due to minimal benefits) (Aliapur, 2010).

4.3.6.3 Environmental indicators

Since a life cycle approach is recommended in all cases, the same indicators may be used (see *Section 3.3.2: Design for sustainability using Life Cycle Analysis (LCA)).*

In addition, more general monitoring indicators should be implemented to track the volume of tyres recovered and the percentage being sent to each treatment method.

4.3.6.4 Cross-media effects

With respect to direct reuse and retreading, there is a lower immediate environmental impact, but this does not eliminate the need for eventual ELT treatment. In particular, there may be issues concerning tyres that are exported for reuse elsewhere – in which case they may be subject to less rigorous controls on disposal.

The main disadvantage of material recovery processes is the high energy requirements due to the mechanical pre-treatment processes (Nemry, et al., 2008), and so in general the smaller the rubber sizes required the more energy is needed.

While this might suggest that the use of whole tyres in other industries is the best option, it should always be considered from a life cycle perspective. Specifically, use of whole tyres in other industries may prolong the life of the tyre, but may render it useless for recycling later due to the lower quality of the rubber obtained.

In the past, concerns have been raised about the potential for eco-toxic leachates from ELT applications. Under experimental conditions, no evidence of significant eco-toxicity was found (Aliapur, 2010).

4.3.6.5 Operational data

Effective collection and supply chains are required to provide an efficient source of ELTs (WBCSD, 2010). There are no specific regulations governing which methods to apply when recovering used tyres in Europe – each Member State is free to choose its management system according to producer responsibility, taxes or free market. The producer responsibility model adopted in some Member States has been responsible for the rapid rate of improvement in ELT management seen in Europe in recent years. This system appears to be the most suitable and robust for addressing and resolving end of life tyre arisings, in a sustainable manner for the long term, and to achieve a 100% recovery rate, in the most economical way (ETRMA, 2011)

As outlined in the description for this option, the optimal end-uses should be chosen on the basis of an LCA. For material recovery applications, the production of synthetic turf and the manufacture of moulded objects have been identified as particularly beneficial options in previous studies, while benefits in some applications (such as retention basins) are less clear (Aliapur, 2010).

Once the key end-use markets have been selected, the tyres must be processed to the appropriate size and quality. In addition, the market demand for tyre products may be variable, and therefore organisations are likely to need to consider a range of different end uses.

For retreading passenger car tyres, access to suitable casings of high quality is a challenge (only an estimated 20% of tyres removed from cars are suitable for retreading), as well as consumer perceptions over the quality of retreaded tyres (WRAP, 2009). The retreading process itself is well understood and can be implemented on a wide range of tyres (WRAP, 2009).

Reuse of **whole tyres** in this context refers to their application in different industries, as opposed to reuse on vehicles. Common applications include coastal protection, artificial reefs, erosion barriers, sea-walls and off-coast breakwaters, boat fenders) (Nemry, et al., 2008). This market is typically only on a small scale, limited to individual projects (ETRMA, 2014).

There are various technologies available for processing tyres:

- **Mechanical:** ELTs are fed into a mobile or fixed shredder that can produce chips of varying sizes. The cut is performed with shearing crusher two or more parallel axes blades which spin at different speeds (Ramos et al, 2010). If finer material is needed, these chips enter a granulator that, at ambient temperatures, processes the chips into rubber granules while removing the steel (via magnet) and fibre (via shaking screens and wind sifters).
- **Cryogenic:** uses liquid nitrogen to cool the tyre, making it easier to shred (Ramos et al, 2010). ELTs may first be shredded into chips (~50 mm), which are then frozen to temperatures below -80˚C in a freezing tunnel. The resulting rubber is brittle and glass-like, and therefore can be shattered into small pieces in a hammer mill.
- An emerging technique is to use **high pressure water jets** to mill tyres, where initial studies show environmental benefits over traditional granulation techniques (Micro Europe, 2011).

The environmental impact of cryogenic methods is considerably greater compared to ambient methods due to the energy consumption needed to maintain the cold temperatures (Aliapur, 2010). A comparison of cryogenic techniques compared to traditional (compression granulation and successive shredding granulation) is shown in Table 4-8.

Table 4-8: Comparison of the environmental impacts using ambient granulation compared to cryogenic

Environmental impact	Traditional	Cryogenic	% difference
Primary energy consumption (GJ)	3	9	200%
Emissions of greenhouse gas of fossil origin (kg eq. CO2)	39	369	846%
Acidifying gas (g eq. SO2)	243	2031	736%
Emissions contributing to tropospheric ozone (g eq. ethylene)	5.1	15.7	208%
Consumption of non-renewable resources (kg eq Sb)	0.3	2.5	733%
Water consumption (m3)	0.66	9.4	1324%
Waste contributing to eutrophication (g eq. PO4)	23	115	400%
Waste production (t)	0.34	0.66	94%

Notes: results for granulation stage with a reference flow of 1 tonne of tyres entering the process. The traditional scenario corresponds to the distribution in France between successive grinding and compression techniques

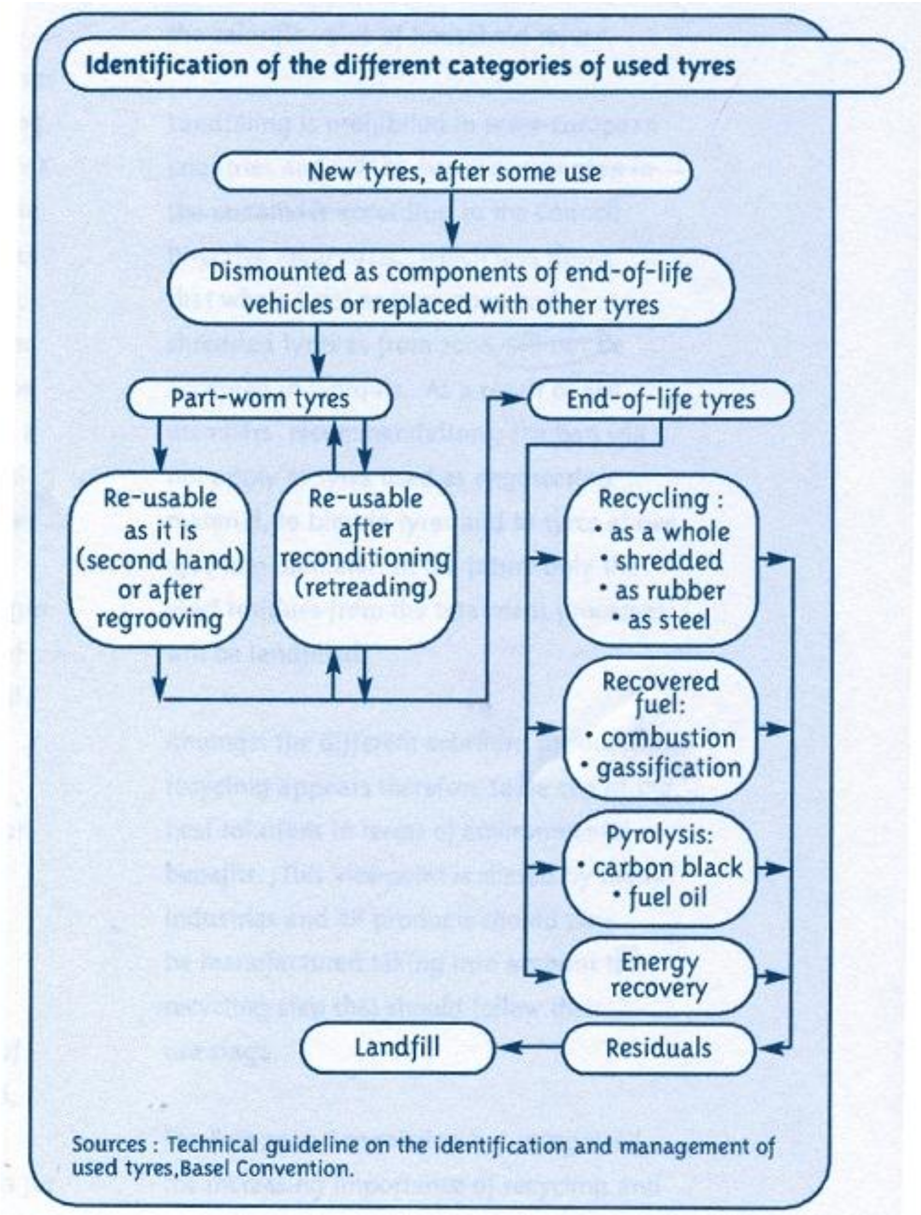
Source: (Aliapur, 2010)

Nevertheless, this comparison is on the basis of environmental impacts only and does not consider the quality of the granulate. Namely, ambient grinding provides relatively coarse crumb rubber material, while the more expensive and energy intensive cryogenic grinding is typically used to obtain finer material.

4.3.6.6 Applicability

The condition of a recovered tyre can determine the suitability of different treatment options to a large extent. Figure 4-12 outlines the suitability of different treatment options on this basis.

Figure 4-12: Suitability of different treatment options depending on condition of tyre



Source: http://www.etrma.org/tyres/ELTs

4.3.6.7 Economics

Experience shows that, in general, the greater the number of ELTs taken in, the more cost efficient the processing system becomes (WBCSD, 2010). Establishing large-scale end-use markets are therefore helpful in allowing a more stable market base, which provide greater reliability and economies of scale – examples of such markets include tyre-derived aggregates and tyre-derived fuel (WBCSD, 2010).

4.3.6.8 Driving force for implementation

The tyre recycling industry has expanded due to many factors, including legal pressure, the availability of size reduction technologies and the emergence of economically viable applications for recycled rubber products (Reschner, 2003).

Relevant legislation in Europe includes:

- The Directive on the Landfill of Waste (1999/31/EC), which banned the landfill of certain whole and shredded tyres effective July 2003 and July 2006.
- The End-of-Life Vehicle Directive (2000/53/EC) sets a target of 95% recovery by 2015 for vehicles below 3.5 tonnes, and therefore indirectly sets targets for tyres. Waste tyres can account for up to 5% of an ELV by weight, and are relatively easy to dismount and recover (Reschner, 2003).
- The Waste Incineration Directive (2000/76/EC) aims to limit emissions (including dust, HCl, HF, NOx, dioxins and heavy metals) from incineration of waste. This may prevent incineration of tyres in facilities that do not meet these standards (Reschner, 2003).

4.3.6.9 Emerging techniques

There are several emerging fields for ELT applications, including recovery in foundries, thermolysis, gasification and pyrolysis (Aliapur, 2010), (Ramos et al, 2010).

4.3.6.10 Reference organisations

N/A

4.3.6.11 Reference literature

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4.3.7 Best practices for other automotive components and materials

4.3.7.1 Description

An ELV contains many other components that must be treated at the ELV stage to minimise overall environmental impacts. Due to the importance of these components, the reader is referred to guidance outlined in Box 4-2

Box 4-2: Recommended guidance for best practice in end-of-life treatment of additional automotive components and materials

Additional guidance is provided in the **Reference Document on the Best Available Techniques in the non-ferrous metals industries** (European Commission, 2001), which is relevant to the treatment of batteries and catalysts:

- Recovery of lead, nickel, cadmium and other materials from batteries;
- Recovery of precious metals from automotive catalysts;
- Measures to reduce the environmental impact of battery breaking, including treatment of contaminated water, use of polypropylene from the crushed battery cases etc.

At the time of writing, the guidance document on non-ferrous metal industries is currently under revision (draft in process). For the latest documents, please refer to the online repository[35].

General best practices are covered under guidance **Reference Document on the Best Available Techniques (BREF) for the Waste Treatment Industries** (European Commission, 2006), which includes several aspects of particular relevance to the automotive industry:

- Treatment of waste containing mercury (e.g. lamps, batteries);
- Treatment of fluids (oil filters, steering, brake and transmission oils, antifreeze);

At the time of writing, the guidance document on waste treatment industries is currently under revision (forthcoming). For the latest documents, please refer to the online repository[36].

A forthcoming **Sectoral Reference document on *Best Environmental Management Practices for the manufacture of electrical and electronic equipment*** will cover processes that are applicable to many automotive electronic systems.

This document will be available on the JRC's website[37].

4.3.7.2 Reference literature

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5 Annex A: Additional background material

5.1 Overview

This Annex contains additional technical material that was presented at the first meeting of the Technical Working Group, which has been removed from the main body of the background report following feedback from the experts.

5.1.1 Material selection with end-of-life considerations

SUMMARY OVERVIEW:				
Decisions on material selection are best managed within a LCA framework. Specific considerations relevant to material selection and the subsequent impacts on the potential for recovery, reuse and recyclability of ELVs are outlined here. This aspect is important because the resulting assumptions on the share and effectiveness of different ELV treatment routes will affect the results of the LCA.				
Relevant life cycle stages				
Management	**Design**	Supply chain	**Manufacturing**	**End-of-life**
Main environmental benefits				
Energy consumption	**Resource use and waste**	Water use & consumption	**Emissions to air, water, soil**	Ecosystems & biodiversity
Environmental indicators				
• Vehicle design decisions made within a formalised framework to minimise contamination and achieve high recyclability (% of design changes)				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Integrating Life Cycle Assessment into vehicle design management			
Related BEMPs	• Design for dismantling; • ELV logistics and operations • Best practice ELV treatment for specific components			

5.1.1.1 Description

Material choice is one of the key elements in vehicle design in order to ensure that the environmental impacts at the end-of-life stage are minimised. However, this is a challenging task due to the complexity of the vehicle components, as well as the need to balance many factors such as performance, safety and recyclability. For example, the increasing fraction of plastics and aluminium in modern vehicles, as well as the introduction of carbon fibre, are likely to make recycling more challenging. Yet the use of lightweight materials such as these will improve the fuel efficiency of vehicles during the use stage. These trade-offs are best managed using a life cycle approach (see *Section 3.3.2*).

The most important issue to recognise is that choosing materials that are more recyclable does not automatically mean that they are more environmentally benign, or have better life cycle performance. Nevertheless, there is still a role for overarching principles focussing on material selection for several reasons:

- To ensure that options for recycling are not fundamentally restricted by the choice of materials. Ultimately, the overall recyclability of any product will also be determined by the

methods of assembly/disassembly (see *Section 3.3.2* and market conditions such as the price for recycled materials (which are subject to variations);

- To reduce the burden on manufacturers when trying to optimise environmental performance. The potential choice of materials and combinations thereof are so numerous that conducting a life cycle assessment on all of these would be extremely time-consuming and expensive.

Therefore, some simple principles are presented here to help guide the initial choice of materials, while more detailed optimisation can take place using life cycle assessment at a later stage.

There are two main factors to consider:

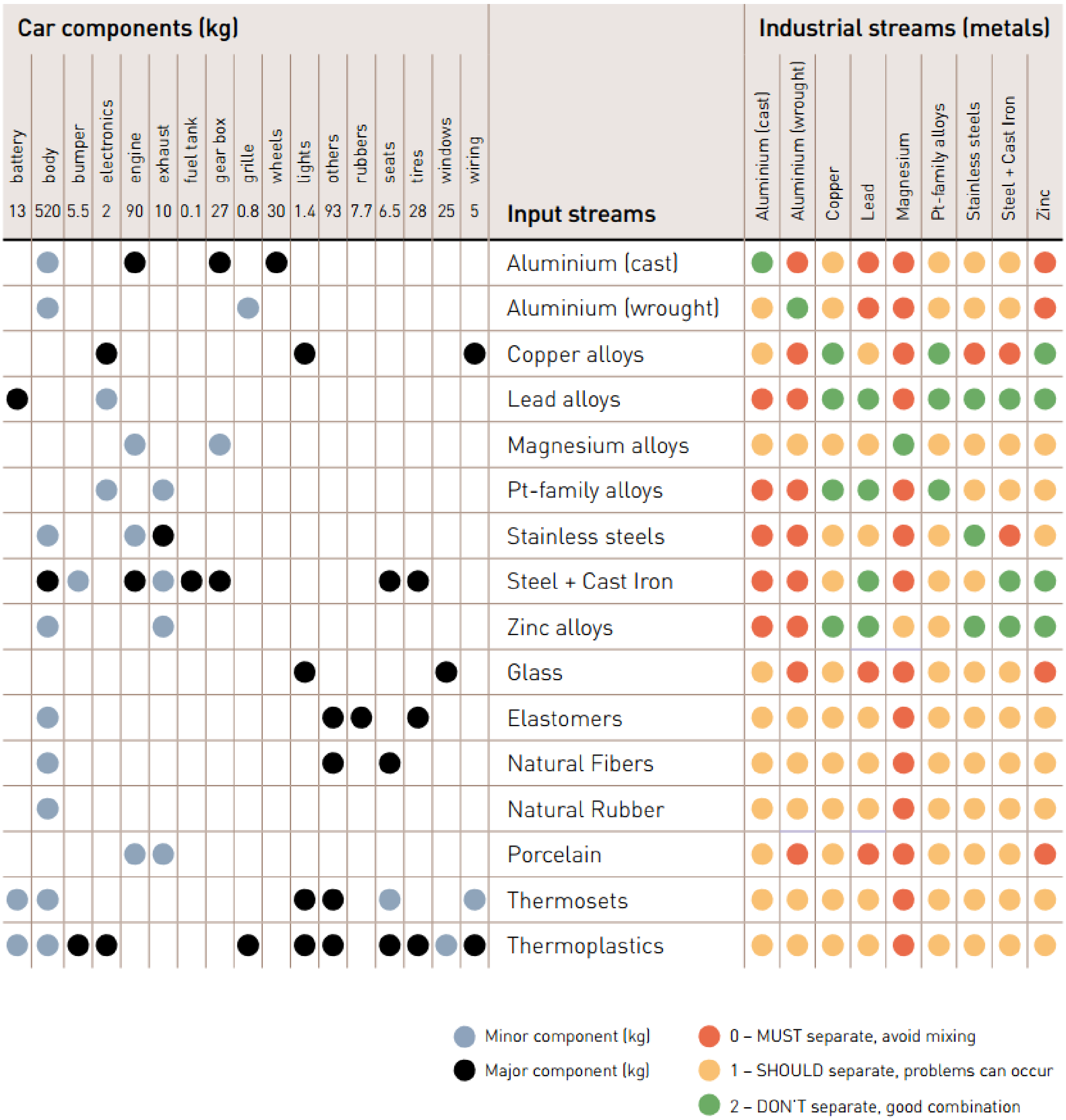
1. **Minimise contamination to prevent loss of recycled material quality;**
2. **Selection of materials that are highly recyclable under expected ELV treatment technology scenarios.**

Option 1. Minimise contamination to prevent loss of recycled material quality

Recycled material quality is highly influenced by the contamination rate. If materials that are not thermodynamically compatible cannot be separated through dismantling or in the shredder, they will be lost into one of the recyclate streams.

Figure 5-1 shows how recycling factors for various materials may be limited, based on liberation, sorting and thermodynamic factors. For example, if aluminium joined to steel goes to a steel-scrap smelter, the aluminium will be lost as alumina (Al2O3) to the slag after the deoxidation process during steel-making (UNEP, 2013). If fibre-reinforced plastics go to any metal smelting operation, they will be lost (UNEP, 2013).

Figure 5-1: Best practice for separation of car components to enable high quality metal recovery



Source: (UNEP, 2013)

General design criteria to reduce contamination are (Froelich et al, 2007), (de Medina et al, 2007):

- **Selecting materials and connectors that are compatible**. Avoiding incompatible materials can improve the feasibility of recycling as well as the quality of the recycled material. For example, Toyota have committed to minimising use of PVC in vehicles, as it requires mono stream separation, and is a common contaminant of post-shredder recyclate (Toyota - personal comm., 2014). The compatibility is assessed according to the influence on mechanical characteristics of the recycled metal and sorting process extraction rates;
- **Selecting materials that are more easily separated**;
    - Assess the ductility of metals. Ductile metal can be considered one of the major sources of scrap defects in the shredding process. Ductility assessment provides an essential method of forecasting whether the shredding process is able to allow material liberation with a low rate of contaminated scraps.
    - Plastic auto parts made of mixed plastics are generally more difficult to be dismantled or separated than metal parts.

- **Choosing part geometry to enable better disassembly** (see *Section 5.1.2: Design for dismantling*).

Option 2. Selection of materials that are highly recyclable under expected ELV treatment technology scenarios

In order to optimise the resource cycle, knowledge of recycling processes and materials have to be combined with that of the design of the product. Various evaluation tools are available to help quickly screen materials and designs in terms of their overall recyclability and recoverability. As noted above, the interactions between different performance, economic and technical factors are highly complex. The best way to appreciate the environmental impact of material selection is to consider the product life cycle. However, undertaking an LCA requires significant resources and therefore initial screening of materials can help to reduce the analytical burden.

While simple tools can be useful for initial screening, more sophisticated tools should also be used to optimise material selection. Many manufacturers have also adopted a simultaneous engineering approach that allows the number of parts in a vehicle to be reduced by integrating functions (de Medina et al, 2007).

Evaluation tools can also be used to assess the benefits of developing new materials for use in vehicles. For example, plastics used in vehicles must possess high rigidity and impact resistance, and must not deteriorate easily when recycled. To meet these criteria, Toyota has developed its own Toyota Super Olefin Polymer (TSOP), a thermoplastic which has superior recyclability to conventional reinforced composite polypropylene (PP). PP can only be recycled two or three times, whereas TSOP can be recycled between 20 and 30 times whilst still maintaining its characteristics (Toyota - personal comm., 2014).

Ford have focussed on the development of *sustainable materials* for use in their vehicles, and their bio-based material portfolio now includes eight materials in production (including coconut-based composite materials, recycled cotton and soy foam) (Ford - personal comm., 2014). Ford used an LCA to understand the potential benefits and tradeoffs associated with the implementation of bio-based composite materials in automotive component production (Boland, et al., 2014). The life cycle primary energy consumption and global warming potential (GWP) were evaluated for grill shutter housing made of (i) cellulose-fibre reinforced composites and; (ii) glass-fibre reinforced composites. The study found that bio-based components reduced the life cycle energy by 9.6% and GWP by 20.7%, This was due to the use of biomass as process energy, the impact of carbon sequestration, and the material's lightweighting effect (Boland, et al., 2014).

5.1.1.2 Achieved environmental benefits

The environmental benefits can only be quantified on a case-by-case basis. Broadly speaking, recovering metals requires less energy than extracting the low grade ores. For example, the ratio of energy for production of primary metal to energy for production of secondary metal is 36:1 for magnesium, 20:1 for aluminium, and 6.2:1 for copper (Villalba, et al., 2004). Materials must be well sorted and separated in order to be easily processed with minimal losses (UNEP, 2013).

Furthermore, natural-fibre reinforced plastic composite materials have become a common replacement for mineral reinforced polymers. The advantages of these natural-fibre composites include low cost, low density, renewable content and similar specific strength properties. The use of a renewable feedstock in place of fiberglass or mineral reinforcements reduce the life cycle impacts in numerous ways (Boland, et al., 2014).

Examples of environmental benefits achieved for several specific components are provided in *Section 4.3: Best practice ELV treatment for specific components*.

5.1.1.3 Environmental indicators

Since a life cycle approach is recommended in all cases, the same indicators may be used (see *Section 3.3.2*).

Specific monitoring indicators can be used, such as the compatibility of the materials involved (Toyota - personal comm., 2014). In addition, more general monitoring indicators should be implemented to track progress. There are no standardised measurements for optimal material selection across

manufacturers. However, indirect indicators can be measured further down the ELV treatment chain, such as industry standard metrics focussing on component/material recovery, reuse and recycling rate. The following are suggested based on the End-of-Life Vehicle Directive reporting requirements, including:

- Mass of the vehicle;
- Recyclability rate (%);
- Recoverability rate (%).

5.1.1.4 Cross-media effects

The selection of materials has an impact at every stage of the life cycle of a vehicle and cannot be considered only in terms of the end-of-life of a vehicle. For example, the recycled foam used by Ford in seat padding, is heavier than that of virgin material, and therefore will have an impact throughout the in-use phase of the vehicle (Ford - personal comm., 2014).

The key goal of the best practices outlined in this section is to improve overall environmental impacts by increasing recyclability while maintaining functionality and performance.

Focussing only on "Design for Recycling" would disregard other important factors, such as energy-efficiency considerations. Therefore, material selection factors should be considered as a subset of overall sustainable design. When properly assessed over the life cycle, any cross-media effects will be identified and minimised where possible (see Section *3.3.2* for further details).

5.1.1.5 Operational data

Option 1. Minimise contamination to prevent loss of recycled material quality

Metals

Recommendations to reduce contamination and improve scrap metal quality are outlined in Table 5-1, along with their relevance and impact according to the expected ELV treatment method.

Table 5-1: Design issues affecting recyclability of metallic components depending on ELV process

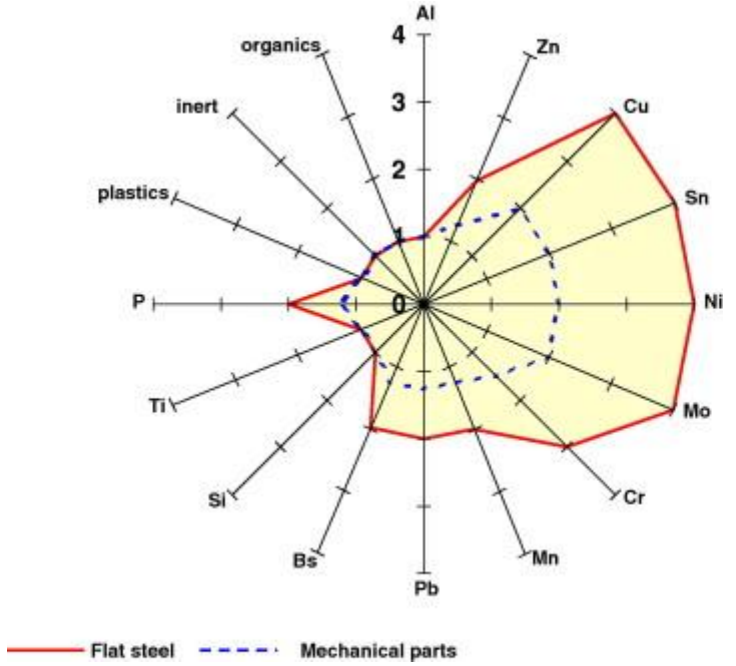
Requirements	Shredding only	Shredding and dismantling	Dismantling only
Choice of associated materials according to material compatibility tables	✓✓✓	✓✓	✓✓
Choice of connection type and nature according to material compatibility tables	✓✓✓	✓✓	✓✓
Decreasing number of alloys used in vehicle	✓✓	✓✓	✓✓
Increasing recycled material content	✓✓✓	✓✓✓	✓✓✓
Avoiding alloys which do not belong to major groups	✓✓	✓	✓
Adapting metallic parts to ensure breakup during shredding	✓✓✓	✓✓	**n/a**

Notes: ✓✓✓=High benefit; ✓✓=Medium benefit; ✓=Some benefit; n/a = not compatible

Source: (Froelich et al, 2007)

Figure 5-2 shows the criticality of different contaminants for flat steel (which has a lower tolerance to residuals due to the need for high purity to ensure good surface quality) and mechanical steel parts (which are able to accept higher contents of contaminants). For steel, the major contaminants are copper, tin, nickel and molybdenum, which may not be fully extracted during metallurgical processes.

Figure 5-2: Contaminant criticality with steel



Source: (Froelich et al, 2007)

Compatibility matrices are a helpful decision-support tool. Table 5-2 shows the compatibilities of metallic residuals for different aluminium alloys. In this case, the main contaminant is iron, as well as copper and zinc. Welding alloys are the most sensitive since they are the purest alloys used in vehicles.

Table 5-2: Alloy compatibility for aluminium

Alloys	MI	MII	MIII	MIV	MV	MVI	MVII	C1	C3	C5	C6	C7
MI (Al Si Cu X)	+											
MII (Al Cu Mg Ti)	−	+										
MIII (Al Si Mg1)	+	O	+									
MIV (Al Si Mg)	+	−	O	+								
MV (Al Si Mg)	−	−	−	O	+							
MVI (Al Mg)	O	−	−	−	−	+						
MVII (Al Si)	−	−	−	O	+	O	+					
C1 (1XXX)	−	−	−	−	−	−	−	+				
C3 (3XXX)	−	−	−	−	−	O	−	−	+			
C5 (5XXX)	−	−	−	−	−	+	−	−	−	+		
C6 (6XXX)	−	−	−	O	O	−	O	−	−	−	+	
C7 (7XXX)	−	−	−	−	−	−	−	−	−	−	−	+

Notes: + = Good compatibility; O = Compatible under certain conditions; - =Incompatible. The MX family is composed of moulding alloys while the CX family groups welding alloys.

Source: (Froelich et al, 2007)

Plastics

Currently one of the main challenges of recycling is how to deal with the plastic fraction. Mixing plastics that have incompatible recycling processes can contaminate the recovered materials and

make recycling more difficult if not impossible. Designers can reduce material contamination by manufacturing parts out of the same plastic material, or with compatible materials. Again, compatibility matrices can be useful here - an example compatibility matrix for plastics is shown in Table 5-3.

Table 5-3: Example compatibility matrix for different plastic types

	ABS	PA	PC	PE	PMMA	POM	PP	PBT	PVC	PC+ PBT	ABS+ PC
ABS	+										
PA	O	+									
PC	O	-	+								
PE	-	-	-	+							
PMMA	+	-	O	-	+						
POM	-	-	-	-	-	+					
PP	-	O	-	O	-	-	+				
PBT	O	O	+	-	-	O	-	+			
PVC	O	-	-	-	+	O	-	O	+		
PC+PBT	O	O	+	-	O	O	-	+	O	+	
ABS+PC	+	O	+	-	O	-	-	O	O	O	+

Notes: 1=Good compatibility; 2=Compatible under certain conditions; 3=Incompatible

Source: (de Medina, 2006).

In addition, paint and glue are two common contaminants of potentially recoverable materials; by reducing the amount of these substances used in the design of the vehicle, it is possible to improve the recycling rate of other materials within the vehicle (Nemry, et al., 2008).

Option 2. Use evaluation tools to ensure that the materials chosen are highly recyclable under expected ELV treatment technology scenarios

Environmental requirements for product design have been introduced at various levels of intensity by many car manufacturers around the world. Nevertheless, there is still a need for tools that can incorporate economic aspects at a regional level (de Medina et al, 2007).

There are many possible evaluation tools available. In this section we present a brief overview of a simple tool and a more complex tool to illustrate the concepts.

An example of a simple tool is the “Recyclability Index”, which provides a measure of the ability of a material to regain its valued properties through a recycling process (Villalba, et al., 2004). This simple tool may be appropriate for an initial screen, especially for small suppliers who would not necessarily benefit from highly complex modelling. A material that has a recyclability index of 1 means that there is no difference between the recycled and the virgin material (first-production form) – i.e. the recycled material is able to regain all the properties the material had in its virgin form. Components that can be reused directly would have a recyclability index close to 1, and materials that are easily recycled would also have indices close to 1 (Villalba, et al., 2004). The recyclability index can be calculated based on current market prices for new and recycled products. This can provide a useful first indication, but future values may differ (e.g. due to changes in the price of recycled material, labour costs, and the introduction of new technologies to recover and recycle any given material).

A more sophisticated tool is better suited to large manufacturers. The OPERA (Overseas Program for Economic Recycling Analyses) software is an example of a more sophisticated evaluation tool that can help designers to simulate recycling potential (de Medina et al, 2007). The software is used to facilitate various decisions (Nissan, n.d.):

- The recyclability rate and recycling cost are calculated on the basis of design data. It incorporates different materials selection criteria into car design including materials recyclability, plastic compatibility, alternative joinings and other manufacturing processes that can impact the disassembling and recycling phase;

- Simulations are run based on actual recycling operations, the user entering the parts, dismantling tools and work operations involved;
- Using the common database shared by Renault and Nissan, the recyclability rate and recycling cost of ELVs can be calculated according to the recycling situation in individual European countries.

Renault has also created educational and design guidance tools to be used by all design engineers. The *Norme Eco-conception 00-10-060/2002* provides guidance on materials selection for recycling, to encourage a higher level of recyclability in new car models. The guidance places particular emphasis on plastics, recommending not only the type of material, but also the assembly joining process (de Medina, 2006).

5.1.1.6 Applicability

The main application is likely to be to the non-metallic fractions, which are typically more challenging to recycle. Design is vital for ensuring materials can be separated and recovered, and this in turn makes recycling operations more viable.

However, this best practice can also improve material selection for metallic components. As an example, an electric motor was redesigned according to the principles outlined above. The materials were mainly of steel and copper, which normally do not present any problems for recycling. However, in this case the high ductility of the copper, as well as the connection between the copper coil and the foliated steel rotor meant that the materials could not be recovered in the shredding process (see Figure 5-3). Since copper is an important contaminant of recycled steel, the subsequent quality of material was reduced. During redesign, the armature material was changed to low ductility steel alloys. This allowed the complete separation and recovery of the copper.

Figure 5-3: Improvements in electric motor shredding operations due to material selection

Shredder problems before component redesign

Separation after material changes

Source: (Froelich et al, 2007)

5.1.1.7 Economics

The automotive industry is currently dependent on raw materials (including certain precious metals) for manufacturing, and this represents a major challenge to supply management. Selection of materials to enable better recycling is potentially very beneficial where the manufacturer can retrieve the materials for recycling at a high purity level, at the end of the vehicles life – in such cases there may be more of an economic incentive to select certain materials.

5.1.1.8 Driving force for implementation

A key driver in Europe is the End-of-Life Vehicle Directive (2000/53/EC), which requires the automobile industry to take responsibility for the proper disposal and recycling of end-of-life vehicles. The subsequent Certification ("RRR") Directive (2005/64/EC on reusability, recyclability and

recoverability) further encourages the recycling and recovery of component parts of end-of-life vehicles by obliging manufacturers to incorporate recycling from the vehicle design stage onwards.

Increasing concern over the scarcity of raw materials is another incentive to focus on material selection within vehicles, in order to ensure they can be more effectively recovered at the end-of-life stage. Closing-the-loop, on material recovery, has been an important incentive for Toyota's development of TSOP (Toyota - personal comm., 2014).

5.1.1.9 Reference organisations

Innovative practices relating to material selection referenced in this section included:

- Material compatibility matrices: Joint study involving Renault, shredding companies (Galloo Recycling and CFF Recycling) and metal producers (Pechiney, Arcelor);
- OPERA evaluation tool: Renault-Nissan.

5.1.1.10 Reference literature

Boland et al. (2014). A Life Cycle Assessment of Natural Fiber Reinforced Composites in Automotive Applications. SAE Technical Paper.

De Medina, H; Naveiro, R & Malafaia, A. (2007) Design for recycling International Conference on Engineering Design, ICED 07

De Medina, H. (2006). Eco-design for Materials Selection in Automobile Industry. Available at: http://www.mech.kuleuven.be/lce2006/066.pdf (accessed 04/05/2014).

Froelich et al. (2007). Development of a new methodology to integrate ELV treatment limits into requirements for metal automotive part design. Minerals Engineering. Available at: http://www.sciencedirect.com/science/article/pii/S0892687507001422 (accessed 04/04/2014).

Ford – personal communication (2014) Interview with Kai Neborg of Ford (25/07/2014)

Nemry, F., Leduc, G., Mongelli, I., & Uihlein, A. (2008). Environmental Improvement of Passenger Cars (IMPRO-car). JRC European Commission.

Nissan. (n.d.). OPERA Recycling Simulation System. Available at: http://www.nissan-global.com/EN/DOCUMENT/PDF/ENVIRONMENT/TECHNOLOGY/en_tech_opera.pdf (accessed 01/04/2014).

Toyota, personal Comm. (2014) Barrow, C., & Denis, R. Interview with Christopher Barrow (Senior Specialist) and Ronny Denis (Manager Environmental Affairs) of Toyota Motor Europe. (09/07/2014).

UNEP (2013) Metal recycling. Available at: http://www.unep.org/resourcepanel/Portals/24102/PDFs/Metal_Recycling_Full_Report.pdf (accessed 01/05/2014)

Villalba, G., Segarra, M., Chimenos, J., & Espiell, F. (2004). Using the recyclability index of materials as a tool for design for disassembly. Available at: http://www.sciencedirect.com/science/article/pii/S0921800904001636 (accessed 12/05/2014).

5.1.2 Design for dismantling

SUMMARY OVERVIEW: The feasibility and ease of dismantling components is largely determined at the design stage. Dismantling opportunities can be maximised through careful selection of fasteners, improving access to parts and use of improved tools				
Relevant lifecycle stages				
Management	**Design**	Supply chain	**Manufacturing**	**End-of-life**
Main environmental benefits				
Energy consumption	**Resource use and waste**	Water use & consumption	Emissions to air, water, soil	Ecosystems & biodiversity
Environmental indicators				
• Number of components that qualify as "easy to dismantle" • Time taken for an average worker to dismantle a specific component.				
Benchmarks of excellence				
TBC				
Cross references				
Prerequisites	• Integrating Life Cycle Assessment into vehicle design management			
Related BEMPS	• Material selection with end-of-life considerations; • ELV logistics and operations • Best practice ELV treatment for specific components			

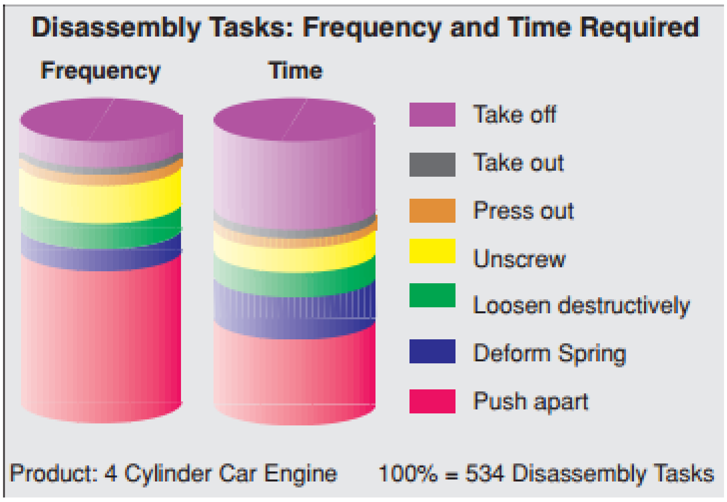
5.1.2.1 Description

"Design for dismantling" principles aim to optimise the separation of components and materials at the end of a product's life. Complex dismantling procedures require greater time and effort, and therefore the economic viability of these operations is reduced (Chiodo, 2005). Thus, increasing the efficiency of the dismantling process is likely to facilitate higher rates of material and component recovery, as well as increasing the value of the recycled material (Nemry, et al., 2008).

Some manufacturers have focussed on post-shredder technologies to achieve targets set in the ELV Directive, while others have chosen to prioritise higher levels of dismantling (de Medina et al, 2007). For the purposes of compliance with the ELV Directive, either technique is suitable. It appears that many European manufacturers prefer the post-shredder recycling option. Nevertheless, there are examples of positive results achieved through higher dismantling, particularly from Japanese manufacturers. For certain components, dismantling may be preferable to post-shredder treatment, particularly where manufacturers are able to reclaim the materials and incorporate them into new parts, thus establishing closed-loop recycling processes and enhancing security of supply.

As an illustration, some typical dismantling operations required for an engine are shown in Figure 5-4.

Figure 5-4: Operations required for disassembly of an engine



Source: (Steinhilper, 2010)

However, dismantling is only possible to the extent where joinings can be loosened without damaging a part. For example, epoxy seals of electric windings, spot welds, joinings obtained by press-forming, forging etc. cannot be disassembled (Steinhilper, 2010).

Therefore, the focus of this section is on general approaches that relate to methods of joining generic components, as well as facilitating the ease of the disassembly process. Broadly, three main factors affect the feasibility and ease of dismantling:

1. The type and number of fasteners

The choice of connections between subassemblies, components and materials can have a significant impact on the ease of disassembly. The main approach to improve dismantling procedures is to minimise the number and type of fasteners. However, this must be achieved without compromising the structural qualities of the assembly by using too few or inadequate fasteners (Chiodo, 2005).

- The use of **snap-fits** in particular is recommended in (Chiodo, 2005), since a component that snaps on can be inserted in seconds, while a component that is screwed on might take minutes to fasten correctly. This time saving is also reflected in the time taken to dismantle the component (MVDA - personal comm., 2014). However, the durability of such components should be considered from a life cycle perspective.
- **Avoiding the use of adhesives** is often recommended where possible, as these represent a common contaminant of the recyclate removed from an ELV (Nemry, et al., 2008).

2. Visibility and access

Simplifying access to different components and making the points of disassembly clearly visible will assist in dismantling procedures. At the design stage, 3D Computer Aided Design (CAD) simulation can be used to simulate the disassembly of products. In addition, human-interaction peripherals (such as motion trackers) can be used to monitor and time the actions required for disassembly. This can be used to test models and evaluate modifications that would improve the ease of part removal from the vehicle. Aspects that should be considered include (Chiodo, 2005):

- **Minimising the number of components** used in an assembly, either by integrating parts or through system re-design;
- **Separating working components** into modular sub-assemblies;
- **Ensuring good access** to components and fasteners.

In addition, markings can be added to vehicle parts, to clearly indicate the most effective points for dismantling or depollution, thereby promoting greater awareness (and uptake) of potential opportunities (INDRA - personal comm., 2014) .

3. **Tools or procedures required**

Some components and/or fastener types require specific tools for disconnection - in these cases, there are two main methods to improve disassembly:

- **The provision/use of standardised tools**. This can be an important factor in terms of reducing working time and improving the recovery of components (for example by reducing tearing) (Toyota Motor Corporation, 2013);
- **Active Disassembly using Smart Materials (ADSM)** involves the disassembly of components using some external stimulus (such as heat) rather than fastener-specific tools. “Smart” materials, such as shape memory polymers and shape memory alloys, revert to a pre-set shape when exposed to specific temperatures; a process that can result in self-disassembly of components. For example, when exposed to a trigger temperature, the thread on a screw could reduce, allowing the screw to dislodge itself without external stimuli (Chiodo, 2005).

The key factors that affect dismantling are summarised in Table 5-4, along with the potential opportunities for improvement discussed above.

Table 5-4: Summary of factors affecting the feasibility and ease of dismantling

Factors	Improvement opportunities
Type and number of fasteners	• Select fasteners that are easy to disassemble • Reduce the number and type of fasteners • Avoid use of adhesives where possible
Visibility and access	• Use CAD-aided design to improve access, layout and ease of removal from the vehicle • Facilitate access to fasteners (e.g. through holes) and avoid using hidden links where possible • Use markings to guide dismantlers
Tools or procedures required	• Make use of improved and standardised tools • Make use of Active Disassembly using Smart Materials (ADSM)

Source: Adapted from (ECO 3E, 2014), (Chiodo, 2005) and (Nemry, et al., 2008).

An additional factor is the choice of materials, which is described in detail in *Section 5.1.1: Material selection.*

5.1.2.2 Achieved environmental benefits

Adopting “design for dismantling” principles can make components more available for re-use or recycling at their end-of-life, thereby reducing the resources required to manufacture products from new.

The environmental benefits can only be quantified on a case by case basis, as the net environmental impact will depend on the specific materials or components involved and their subsequent treatment. However, this best practice will help to ensure that more materials are able to be recovered in a less contaminated, and more easily identifiable form.

5.1.2.3 Environmental indicators

While there are no standardised measurements for the ease of dismantling a specific component, general indicators could include:

- Number of components that qualify as “easy to dismantle”;
- Time taken for an average worker to dismantle a specific component.

For example, Toyota completely dismantles every new model in the design stage, and uses the time taken for dismantling and the number of components removed, as indicators of the 'dismantlabillity' of the vehicle (Toyota - personal comm., 2014).

Indirect indicators can be measured further down the ELV treatment chain in terms of industry standard metrics such as component/material recovery, reuse and recycling rates. The indicators for these aspects are suggested based on the End-of-Life Vehicle Directive reporting requirements:

- Mass of the vehicle and mass of material taken into account at the dismantling step;
- Recyclability rate (%);
- Recoverability rate (%).

5.1.2.4 Cross-media effects

In all cases, the environmental benefits of dismantling should be compared to alternative end-of-life options such as post-shredder recovery. ARN, the body responsible for overseeing the Dutch ELV disposal system, uses a tool called Ecotest to assess the environmental impact of post-shredder recovery versus increased dismantling. Ecotest takes into account relative changes in recycling rate, CO_2 footprint, toxicity (when applicable) as well as financial cost (ARN - personal comm., 2014). The relevance of assumptions made in such analysis must be carefully assessed to ensure they reflect the real world situation as closely as possible, taking into account the post-shredder recovery options that will be used. For example, Volkswagen AG's life cycle assessment of their post-shredder VW-SiCon process concludes that the VW-SiCon process is more environmentally friendly than a scenario in which a vehicle is first dismantled and subsequently recycled mechanically (Krinke, et al., 2005). These findings are not necessarily generalisable – rather, they highlight the need to evaluate options across the life cycle.

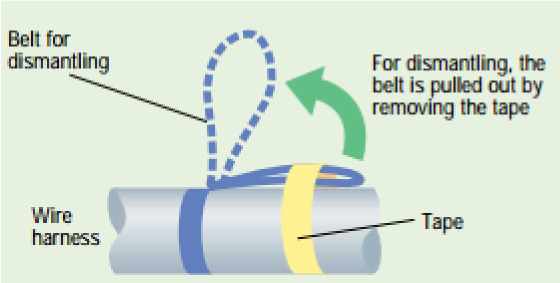
Critical to design for dismantling, is that OEMs tend to focus on designing the car with the in-use phase in mind, which typically represents ~80% of the carbon footprint, rather than the end-of-life stage, which usually only accounts for ~5% of the carbon footprint (ARN - personal comm., 2014). A life cycle assessment should be considered to evaluate trade-offs on a case-by-case basis (see *Section 3.3.2*). For example. the use of adhesive joints can make dismantling and subsequent recycling more challenging; however in some cases adhesive joints are the best option where they allow the use of lighter weight materials that will reduce the overall environmental impacts of the car (RCAR, 2008).

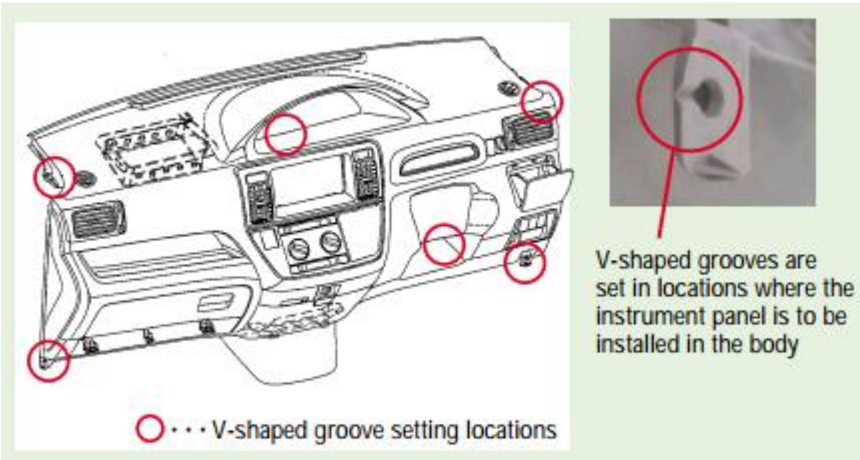
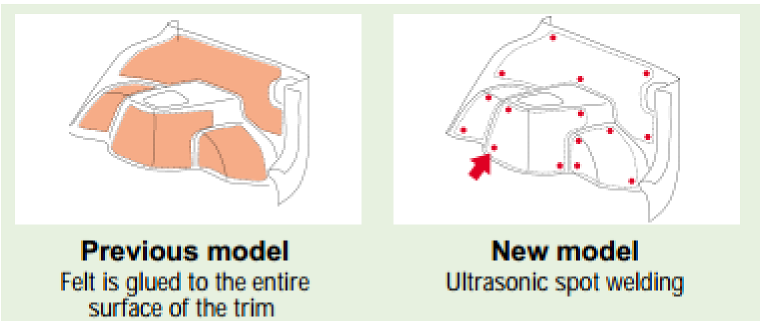
The use of ADSM will have an impact on energy use in vehicle dismantling, dependent on the material used and method of heat application (i.e. radiation, convection or conduction). The trigger temperature for smart materials can range from 65 degrees Celsius to 120 degrees (Chiodo, 2005). A change in the material used in a car would also require a lifecycle assessment to understand the environmental consequences.

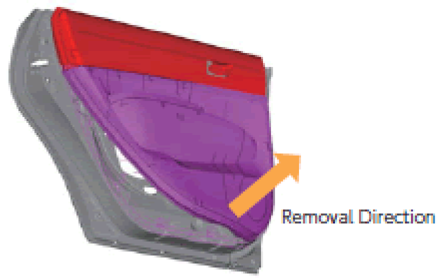
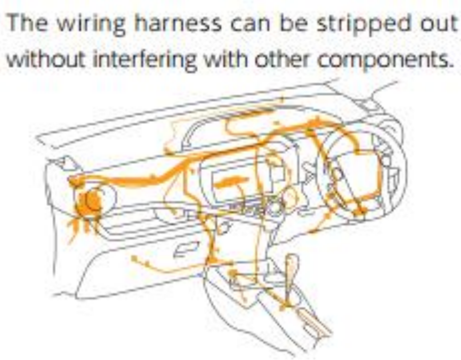
5.1.2.5 Operational data

Examples of best practice methods are outlined in Table 5-5.

Table 5-5: Overview of steps used to reduce total dismantling time implemented by Toyota

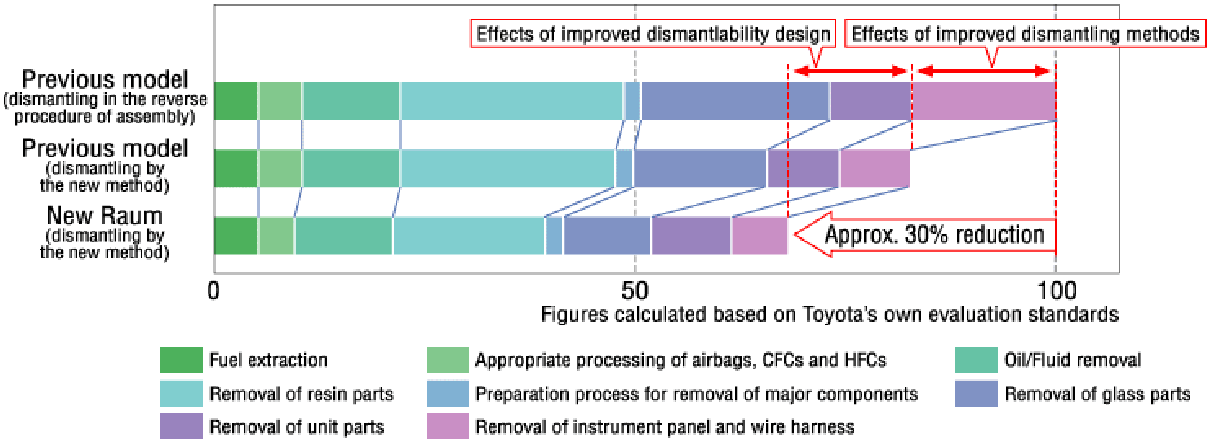
<table>
<tr><th>Improvement opportunities</th><th>Example implementation</th></tr>
<tr><td colspan="2">Type and number of fasteners</td></tr>
<tr><td>Use fastener types that are easy to disassemble (such as snap-fit fasteners)</td><td>Toyota has created wiring harnesses which use pull-tab type grounding terminals. This allows the wiring harnesses to be easily stripped off without interfering with other components (Toyota Motor Corporation, 2013)


New structures include V-shaped grooves in locations where the instrument panel is to be attached to the body. This allows the instrument panel to be removed easily by pulling it away from the body (Toyota Motor Corporation, 2013)

</td></tr>
<tr><td>Reduce the number and type of fasteners</td><td>Toyota has integrated the front bumper on its Raum model with the grille - in the previous model, the bumper consisted of three parts: the front grill, the upper bumper, and the lower bumper. These three parts have been integrated into a single part in the new model, simplifying the dismantling process (Toyota Motor Corporation, 2013)</td></tr>
<tr><td>Avoidance of adhesives where possible</td><td>Toyota have introduced Ultrasonic spot welding to replace glue where attaching soundproofing felt material to the vehicle (Toyota Motor Corporation, 2013)

</td></tr>
</table>

Improvement opportunities	Example implementation
Visibility and access	
CAD-aided design to improve access, layout and ease of removal from the vehicle	Toyota runs computer simulations for the process of removing resin parts. This allows designers to calculate the force necessary for breakage and removal without conducting tests on actual vehicles. Simulations have been used for technologies for wiring harnesses, bumpers, instrument panels and door trim (Toyota global website, 2014) In addition to computer simulations, Toyota completely dismantles every car in the design stage to assess how easy it is to dismantle (Toyota - personal comm., 2014). 
Facilitate access to fasteners (e.g. through holes) and avoid hidden links where possible	 Toyota has developed structural designs that make it easy to dismantle and separate parts, based on surveys of actual conditions at dismantling companies, and is actively adopting these designs for new models. For example, design changes have ensured that fewer components need to be removed before lifting out the hybrid vehicle battery, and that the wiring harness can be stripped out without interfering with other components (Toyota Motor Corporation, 2013)
Use markings to guide dismantlers	Toyota designed an "Easy to Dismantle Mark." This mark is added to vehicle parts, clearly indicating certain points that assist in initial dismantling, such as the positions at which large resin parts can be easily separated and the locations at which holes can be drilled for removing fuel (Toyota Motor Corporation, 2013)
Tools and procedures required	
Use of improved and standardised tools	Toyota redesigned the standard bumper tearing-off device to an improved hoist and hook system. This has resulted in a reduction in price by 90% and reduction in collection time of 45% on average (Toyota global website, 2014) 

Significant improvements in overall dismantling time can be achieved through a combination of the measures described, as shown in Figure 5-5. The time required for dismantling was shortened by 30%, compared to the previous Raum model.

Figure 5-5: Improvements in dismantling time achieved for the Toyota Raum compared to the previous model



Source: (Toyota global website, 2014)

Improvements were made to the dismantling process, including fluid removal and the removal of large resin parts, resulting in increased dismantling efficiency. Toyota applied the following techniques (Toyota global website, 2014):

- Adoption of structures that allow fastened areas to come apart when pulled hard;
- Use of clips instead of screws for securing components whenever possible;
- Parts integration;
- Avoidance of composite materials.

This equates to 30% fewer labour hours required for vehicle dismantling, or the freeing up of time to recover more material and/or components at the same cost (Toyota global website, 2014).

5.1.2.6 Applicability

Overall applicability should be evaluated on the basis of life cycle environmental impacts. The potential environmental gains are likely to be greatest when considering the dismantling of components/materials that are less financially attractive to dismantle (such as plastic and glass components) (Optimat, 2013). The materials and components most relevant are expected to be (Umweltbundesamt GmbH, 2010):

- Plastics (approx. 10 % of ELV weight);
- Tyres (approx. 30 kg/ELV);
- Glass (approx. 25 kg/ELV);
- Rubber (~2%);
- Fluids (~1.7%) and textiles (~1%).

Despite attempts by OEMs to improve vehicle dismantlability (e.g. plastic parts, wiring harnesses etc), in general, ATFs in Europe do not currently make significant use of these design features (ARN - personal comm., 2014), (EGARA - personal comm., 2014) (MVDA - personal comm., 2014). This is due to the costs involved in the removal, storage and transport of materials removed, in comparison to the potential return from sale. However, Toyota have maintained comparatively expensive design-for-dismantling features, despite feedback from ELV stakeholders that they are not made use of at the dismantling stage. Toyota believe that design for dismantling is applicable in Europe, because a vehicle's product life-cycle is such that, at its end-of-life, increased dismantling may be more feasible (Toyota - personal comm., 2014).

The applicability of design for dismantling is further complicated by the fact that the factors affecting ELV treatment are different in every country (e.g. material markets, labour markets, legislation etc) (Toyota - personal comm., 2014). Where ATFs dismantle many different types of vehicle, they may not have the time or resources to understand what materials each vehicle is made of, and how to

dismantle effectively; this becomes particularly pertinent where ATFs are also SMEs (Ford - personal comm., 2014).

Toyota has developed tools to increase the speed of airbag deployment, glass cutting, wiring harness removal and bumper removal. However these are only used in Japan as the conditions do not support pre-shredder dismantling in Europe (Toyota - personal comm., 2014).

5.1.2.7 Economics

Dismantling costs represent one of the most significant cost factors in the overall cost of recycling ELV components, and a key limitation to achieving higher levels of mechanised recycling. This is particularly the case for plastics and glass (Nemry, et al., 2008), (MVDA - personal comm., 2014).

Labour costs are a major contributor to the total cost of dismantling operations; therefore any gains in the efficiency of the dismantling process will have significant economic impacts on subsequent ELV treatment decisions.

5.1.2.8 Driving force for implementation

In Europe, the End-of-Life Vehicle Directive 2000/53/EC requires that: "*dismantling, reuse, and recycling of ELVs and their components should be integrated in the design and production of new vehicles*". Other legislation such as the WEEE Directive 2012/19/EU and the Restriction of the use of certain Hazardous Substances (RoHS) Directive 2011/65/EU also put pressure on manufacturers to adopt sustainable design principles.

The recycling of most metals from ELVs is driven by their economic value. However, in order to achieve the current recycling targets set by ELV Directive 2000/53/EC (85% recycling and 95% recovery by 2015), recycling and recovery of more materials is necessary - even if their recovery is less economically viable (Umweltbundesamt GmbH, 2010).

5.1.2.9 Reference organisations

Design for dismantling processes have been developed and are in use by several car manufacturers. Key examples were shown from Toyota.

5.1.2.10 Reference literature

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6 Glossary

AD	Acidification potential. SO_2 and NO_x emissions are the main causes of acid deposition, which leads to changes in soil and water quality and damage to vegetation, buildings and aquatic life.
AOX	Absorbable organic halides
ASR	Auto Shredder Residue
BAT	Best available techniques
BEMP	Best Environmental Management Practices
BEV	Battery Electric Vehicle. Also referred to as a pure electric vehicle (EV). A vehicle powered solely by electricity stored in on-board batteries, which are charged from the electricity grid
BIW	Body in white (see body shop)
Body shop	Production of the of vehicle body structure including closures (body in white)
BREF	BAT reference document, developed under the IPPC Directive (2008/1/EC)
CO_2	Carbon dioxide, one of the principal GHGs
COD	Chemical Oxygen Demand
EC	European Commission
EMAS	EcoManagement and Audit Scheme
EP	Eutrophication potential. Eutrophication is a process whereby water bodies, such as lakes or rivers, receive excess chemical nutrients — typically compounds containing nitrogen or phosphorus — that stimulate excessive plant growth (e.g. algae).
EV	Electric vehicle
ELV	End-of-life vehicles
GHG	Greenhouse gases. Pollutant emissions from transport and other sources, which contribute to the greenhouse gas effect and climate change.
GWP	Global warming potential
HEV	Hybrid electric vehicle. A vehicle powered by both a conventional engine and an electric battery, which is charged when the engine is used.
HVAC	Heating, Ventilation and Air Conditioning
ICE	Internal combustion engine, as used in conventional vehicles powered by petrol, diesel and natural gas
IPPC	Integrated Pollution Prevention and Control. IPPC applies an integrated environmental approach to the regulation of certain industrial activities
JRC	Joint Research Centre
LCA	Life cycle assessment
LCI	Life cycle inventory
OEM	Original Equipment Manufacturer. Refers to car manufacturers in this document
NOx	Oxides of nitrogen
Paint shop	Application of interior and exterior paint and finish
PANs	Peroxyacyl nitrates
Press shop	Production of finished parts that are pressed out of coiled sheet metal

PHEV	Plug-in hybrid electric vehicle, also known as extended range electric vehicle (ER-EV). Vehicles that are powered by both a conventional engine and an electric battery, which can be charged from the electricity grid. The battery is larger than that in an HEV, but smaller than that in a BEV
PCOP	Photochemical oxidation potential. Measurement of the increased potential of photochemical smog events due to the chemical reaction between sunlight and specific gases released into the atmosphere. These gases include nitrogen oxides (NOx), volatile organic compounds (VOCs), peroxyacyl nitrates (PANs), aldehydes and ozone
PM	Particulate matter. Inhaling particulate matter has been linked to asthma, lung cancer, cardiovascular problems, birth defects and premature death. Subscripts indicate the particle diameter, for example $PM_{2.5}$ denotes fine particles with diameter of 2.5 micrometres or less. Smaller particles are thought to be more damaging to health as they can penetrate further into the gas exchange regions of the lungs.
SO_2	Sulphur dioxide
SOx	Oxides of sulphur (including sulphur dioxide)
VOC	Volatile organic compound

RICARDO-AEA

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR

Tel: 01235 75 3000
Web: www.ricardo-aea.com