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Best Environmental Management Practice in the Fabricated Metal Product Manufacturing sector

Learning from frontrunners

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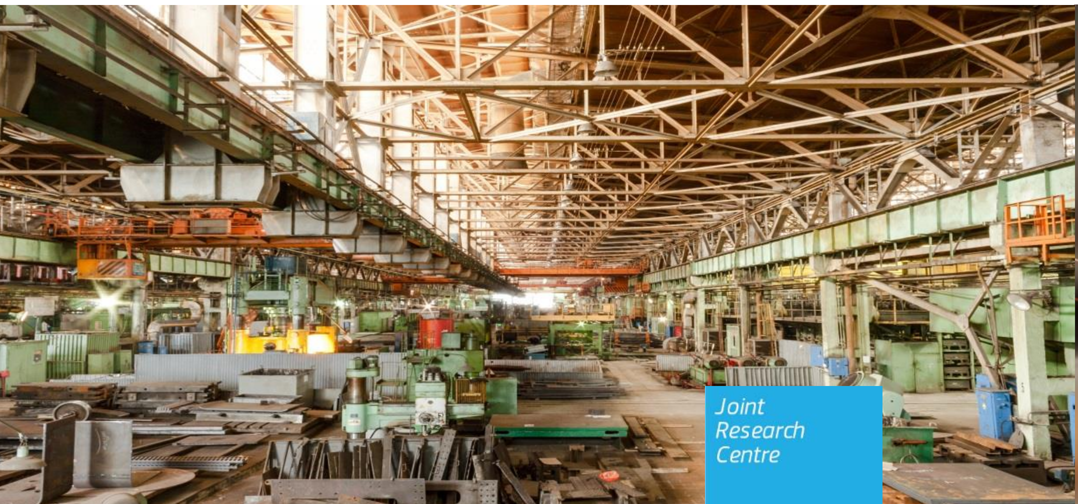

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Best Environmental Management Practice in the Fabricated Metal Products manufacturing sector

Abstract
This report encloses technical information pertinent to the development of Best Environmental Management Practices (BEMPs) for the Sectoral Reference Document on the Fabricated Metal Products manufacturing sector, to be produced by the European Commission according to Article 46 of Regulation (EC) No 1221/2009 (EMAS Regulation).
The BEMPs, both of technological and management nature (identified in close cooperation with a technical working group) address all the relevant environmental aspects of the Fabricated Metal Products manufacturing facilities. The BEMPs described in this report provide guidance on the cross-cutting issues and optimisation of utilities of the manufacturing facilities. Moreover, the BEMPs cover also the most relevant manufacturing processes, looking at energy and material efficiency, protecting and enhancing biodiversity, using of renewable energy and using rationally and effectively chemicals e.g. for cooling of various machining processes.
Each BEMP gives a wide range of information and outlines the achieved environmental benefits, appropriate environmental performance indicators to measure environmental performance against the proposed benchmarks of excellence, economics etc. aiming at giving inspiration and guidance to any company of the sector who wishes to improve its environmental performance.

Contents

Preface

Introduction

This best practice report provides an overview of techniques that may be considered **Best Environmental Management Practices** (BEMPs) in the Fabricated Metal Products manufacturing sector. The document was developed by the European Commission's Joint Research Centre (JRC) on the basis of a background report produced for JRC by its contractor VITO ENV (Belgium) and BiPRO (Germany) and discussions with technical experts via the forum of a Technical Working Group (TWG) comprising experts from industry, academia and NGOs, as well as desk research and interviews with further stakeholders.

This best practice report is intended to be a source of inspiration and guidance for any company of the Fabricated Metal Products manufacturing sector wishing to improve its environmental performance. In parallel, its technical content will be used for the development of an EMAS Sectoral Reference Document (SRD) to be officially adopted by the European Commission.

Figure A.1 shows the different output of this work and their relationship, while further information on the EMAS SRDs, their aim and use and the whole structured development process are outlined 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].

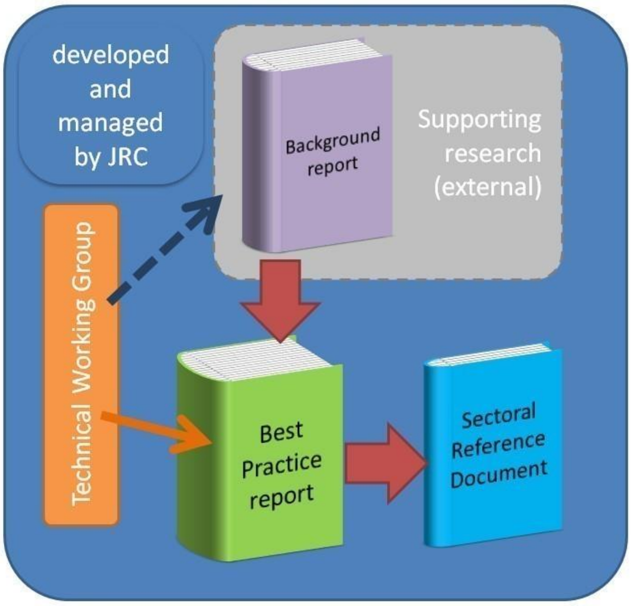

Figure A.1. The relationship between the background report, the best practice report and the Sectoral Reference Document (SRD)

Companies from the Fabricated Metal Products manufacturing sector interested in implementing best practices to improve their environmental performance are recommended to refer to the present Best Practice Report that present them in detail and in their final version.

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

Background

EMAS (the EU Eco-Management and Audit Scheme) is a management tool for companies and other organisations to evaluate, report and improve their environmental performance[2]. To support this aim and according to the provisions of Art. 46 of the EMAS Regulation (EC No. 1221/2009), the European Commission is producing SRDs to provide information and guidance on BEMPs in several priority sectors, including the Fabricated Metal Products manufacturing sector.

Nevertheless, the guidance on BEMP is not only for EMAS registered organisations, but it is rather intended to be a useful reference document for any company that wishes to improve its environmental performance or any actor involved in promoting best environmental performance.

Content

The core element of this report is the BEMPs for the Fabricated Metal Products manufacturing sector.

BEMPs encompass techniques, measures or actions that can be taken to minimise environmental impacts. These can include technologies (such as more efficient tools, equipment and processes) as well as organisational practices (such as chemicals management).

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

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

In other words, BEMPs are demonstrated practices that have the potential to be taken up on a wide scale in the Fabricated Metal Products manufacturing sector, yet at the same time are expected to result in exceptional environmental performance compared to current mainstream practices.

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

Table A.1. Information gathered for each BEMP

Category	Type of information included
Description	Brief technical description of the BEMP including some 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.

[2] Further information on EMAS is available online at www.emas.eu.

Category	Type of information included
Operational data	Operational data that can help understand the implementation of a BEMP, including any issues experienced. This includes actual and facility-specific performance data where possible.
Applicability	Indication of the type of facilities 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, decreased waste charges, etc.).
Driving force for implementation	Factors that have driven or stimulated the implementation of the BEMP by organisation of the sector to date.
Reference organisations	Examples of organisations that have successfully implemented the BEMP.
Reference literature	Literature or other reference material cited in the previous sections of the text on the BEMP.

Wherever possible, for each of the proposed BEMPs, sector-specific Environmental Performance Indicators and Benchmarks of Excellence are also presented. 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 companies in the sector to monitor either the implementation of the BEMPs described or, when possible, directly their environmental performance in relation to the aspects covered by the BEMP.
- *Benchmarks of Excellence* represent the highest environmental standards that have been achieved by companies implementing each related BEMP. These aim to allow all actors in the sector to understand the potential for environmental improvement at the process level. Benchmarks of excellence are not targets for all organisations to reach but rather a measure of what is possible to achieve (under stated conditions) that companies can use to set priorities for action in the framework of continuous improvement of environmental performance.

Conclusions on sector-specific Environmental Performance Indicators and Benchmarks of Excellence were drawn by the TWG at the end of its interaction with the JRC.

Sources of information and development of the document

The information presented in this best practice report was collected and elaborated between December 2014 and December 2017, both as part of the development of a background report by VITO (Belgium), and BiPRO (Germany) under contracts with JRC, and as part of the subsequent interaction with the European TWG established for this sector and related further research and elaboration by JRC.

The main sources of information were scientific literature, technical reports, environmental and/or sustainability reports from companies of the sector that are publicly available, as well as further information obtained directly from stakeholders and experts from the sector through interviews or bilateral exchanges or from members of the technical working group.

Structure

Chapter 1 ('Scope and overview of the sector') provides some background information on the Fabricated Metal Products manufacturing sector:

- Section 1.1 regarding general information about the Fabricated Metal Products manufacturing sector (e.g. number and size of the companies who belong to this sector)
- Section 1.2 regarding the economic relevance of the Fabricated Metal Products manufacturing sector (e.g. turn over)
- Section 1.3 regarding the main environmental aspects and pressures of the Fabricated Metal Products manufacturing sector
- Section 1.4 regarding the role of EMAS on the Fabricated Metal Products manufacturing sector
- Section 1.5 regarding the existing environmental EU policy instruments for the Fabricated Metal Products manufacturing sector
- Section 1.6 regarding the scope of this best practice report

The main content of this report are the BEMPs for the Fabricated Metal Products manufacturing sector, described in Chapters 2 to 4:

Chapter 2 “Cross-cutting measures” gathers practices that can be implemented by any actor of the fabricated metal products manufacturing sector and offer guidance on topics such as applying effective methods for environmental management, a framework for collaboration across and along the value chain, remanufacturing of high value components. Also, it acknowledges the relevant Reference Documents on Best Available Techniques, the so called BRefs;
Chapter 3 “Optimisation of utilities” lists techniques that offer guidance on the improvement of the overall environmental performance of the manufacturing facility, such as optimal lighting, efficient use of compressed air systems, use of renewable energy with energy storage and rainwater collection;
Chapter 4 “Manufacturing processes” provides technical advice and guidance on how to reduce the environmental impacts of the various manufacturing processes applied within the manufacturing sites (e.g. casting, shaping). For instance, some best practices are multi-directional forging, selection of metal working fluids, incremental sheet metal forming etc.

Chapter 5 "Conclusions" summarises the identified key-environmental performance indicators and their metrics, and the benchmarks of excellence for each identified BEMP.

How to use this document

This document is not conceived to be read from beginning to end, but as a working tool for professionals from the sector, willing to improve the environmental performance of their organisation/company and who seek reliable and proven information in order to do so.

Different parts of the document will be of interest and will apply to different professionals and at different stages.

The best way to start using this document is by reading the short section (summary overview) about its structure to understand the content of the different chapters and, in particular, the areas for which BEMPs have been described and how these BEMPs have been grouped.

Then, Chapter 1 would be a good starting point for readers looking for a general understanding of the sector and its environmental aspects and also to understand the scope of this document and the relation between the scope of this document and the existing Reference Documents on Best Available Techniques Reference Documents (the so called BRefs). Those looking for an overview of the BEMPs described in the document could start from Chapter 5 (Conclusions) and in particular with Table 5.1 outlining all BEMPs together with the related environmental performance indicators and benchmarks of excellence, i.e. the exemplary performance level that can be reached in each area. For readers looking for information on how to improve their environmental performance in a specific area, it is recommended to start directly at the concrete description of the BEMPs on that topic, which can be easily found through the table of contents.

A summary overview table for each BEMP at the beginning of each BEMP presents its main elements and provides the reader with preliminary information on the applicability conditions, on the key environmental performance indicators and benchmarks of excellence where appropriate. For readers interested in more detailed information on how to specifically implement the outlined BEMP within their sites, it is recommended to continue reading the main content of the BEMP.

Acknowledgements

This report was prepared by the European Commission's Joint Research Centre in the framework of supporting the development of an EMAS Sectoral Reference Document[3] for the Fabricated Metal products manufacturing sector.

This document is based on different preparatory studies carried out by VITO (Belgium) and BiPRO (Germany). Moreover, a technical working group, comprising a broad spectrum of experts in the fabricating of metal products manufacturing sector, supported the development of this process by providing inputs and feedback. Technical summaries from the meetings of the technical working group are available on the Joint Research Centre's website[4].

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[3] Further information on the development of the EMAS Sectoral Reference Documents is available online at:http://susproc.jrc.ec.europa.eu/activities/emas/documents/DevelopmentSRD.pdf

[4] Further information at: http://susproc.jrc.ec.europa.eu/activities/emas/fab_metal_prod.html

Executive summary

This best practice report describes techniques that are considered **Best Environmental Management Practices (BEMPs)** in the fabricated metal products manufacturing sector. It was produced by the European Commission's Joint Research Centre (JRC), with the support of technical experts and stakeholders from the sector via the forum of a Technical Working Group (TWG).

It is intended to be a source of inspiration and guidance for any company of the fabricated metal products manufacturing sector wishing to improve its environmental performance. In parallel, its technical content will be used for the development of an EMAS Sectoral Reference Document (SRD) for the fabricated metal products manufacturing sector to be officially adopted by the European Commission[5].

Target group

The BEMPs described in this report are relevant for the Fabricated Metal Products manufacturing companies.

Scope

The BEMPs described in this report cover core manufacturing and supporting activities and processes (e.g. casting, shaping, removing, surface treatment processes) of the Fabricated Metal Products manufacturing sector. However, the primary manufacturing activities of iron, steel and non-ferrous metals **are not included** in the scope of the report.

For processes (e.g. coating applications, air emission treatment) that fall in the scope of other existing European Commission's policy and technical documents, this report refers to these documents. Figure A.2 illustrates the activities and environmental aspects of the fabricated metal products manufacturing sector.

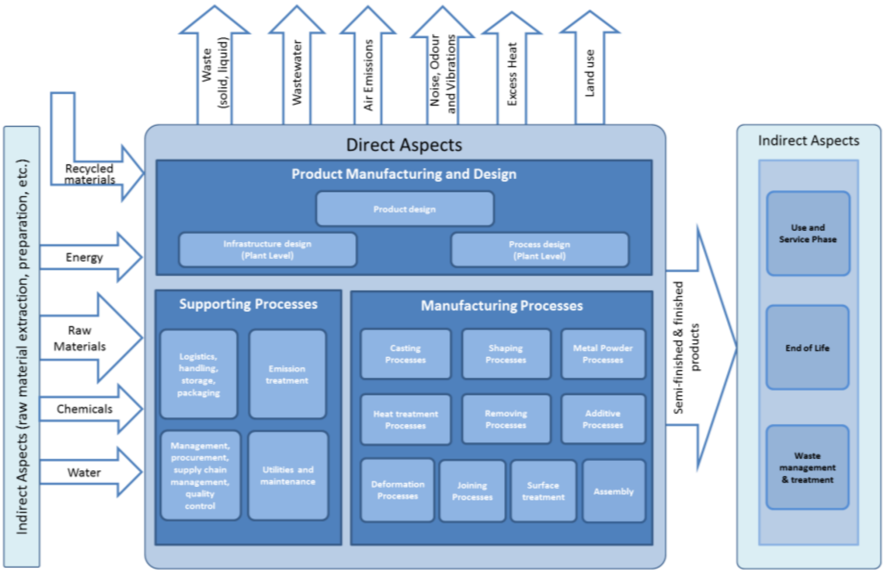


Figure A.2. Overview of the activities and environmental aspects of the fabricated metal products manufacturing sector

[5] Further information on what are the EMAS Sectoral Reference Documents and how these are developed 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 at http://susproc.jrc.ec.europa.eu/activities/emas/documents/DevelopmentSRD.pdf.

Content

The BEMPs are grouped into 3 main areas:

A. Cross-cutting measures

The cross-cutting measures are BEMPs that can be implemented by any actor of the companies from the fabricated metal products manufacturing sector. 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. The BEMPs for cross cutting measures are:

- **Applying effective methods for environmental management** gives an overview on how the existing environmental policy schemes and principles can be integrated into the management systems of the fabricated metal product manufacturing companies.
- **Collaboration and communication along and across the value chain** describes the background on how the companies from the sector can set a cross-sectoral collaboration scheme, throughout the entire value chain.
- **Energy management** describes an overall approach for reducing and optimising the energy use at process level of the Fabricated Metal Products manufacturing companies.
- **Environmentally and sound efficient management of chemicals** which goes beyond the sheer correct handling and storage of chemicals in compliance with legislative requirements and focusses particularly on minimising the amounts of chemicals used and disposed of as well as substituting hazardous chemicals wherever possible.
- **Biodiversity management** outlines the steps that a company should take into account to identify direct and indirect environmental impacts throughout the value chain and own operations.
- **Remanufacturing and high-quality refurbishment of high-value or large series products and components** which describes the framework of using high value materials and pieces in the reassembly into new products.
- **Link to relevant Reference Documents on Best Available Techniques (BREFs[6])** in an individual BEMP, which lists the direct environmental aspects of the fabricated metal products manufacturing companies and how these are covered in the BREFs.

B. Optimisation of utilities

This set of BEMPs is helpful to improve the overall environmental performance of the processes that are implemented within the plant such as lighting, ventilation, use of compressed air etc. The BEMPs of this chapter are:

- **Efficient ventilation** deals with the minimisation of the ventilation needs of the production line, storage rooms, utility rooms, offices etc., results in a better light quality, better working conditions and a lower electricity consumption.
- **Optimal lighting** adapted to the specific needs of the production line, storage rooms, utility rooms, offices etc. results in a better light quality, better working conditions and a lower electricity consumption.
- **Environmental optimisation of cooling systems** deals with the systematic approach of reducing the cooling needs within the manufacturing plant, using and optimising the cooling design.

[6] Further information about the BREFs available online at: http://eippcb.jrc.ec.europa.eu/index.html

- **Rational and efficient use of compressed air systems** by minimising compressed air needs and optimising the system's design and use, results in a lower overall energy use.
- **Use of renewable energy** offers guidance on how a company from the sector can make best use of self-generated or purchased energy (out of the total energy use).
- **Rainwater collection** which aims to reduce the amount of fresh water used for manufacturing and ancillary processes of the fabricated metal products manufacturing companies.

C. Manufacturing processes

This area gathers practices that improve the environmental performance of the manufacturing processes, and the BEMPs listed in this chapter are:

- **Selection of resource-efficient metal working fluids** with a lower environmental impact that result in higher resource efficiency and better environmental performance of the carried out machining operations.
- **Minimisation of lubricoolant use in metal processing** by minimising or avoiding the use of lubricoolants in processing and shaping metal within the manufacturing plants.
- **Incremental Sheet metal forming** as alternative technique for mould making leads to lower material use.
- The implementation of smart tools (switches, software, PLC stearing, etc.) on machines results in a **Reduction of standby energy of metal working machines.**
- **Maintaining material value for metal residues** within the manufacturing site deals with the separate collection and treatment of the different aluminium grades in order to allow higher quality in the recycled materials.
- **Multi-directional forging** may lead to lower material and energy use since it is an alternative resource efficient metal shaping technique, which is applied for complex geometric pieces in large series.
- Manufacturing processes that combine two or more established processes are described in **Hybrid machining as a method to reduce energy use**.
- **Use of predictive control for paint booth HVAC management** by monitoring the actual temperature and humidity of the incoming air in the paint booth on the one hand and conditioning this air to the optimal window for curing on the other hand. This results in a lower energy use HVAC unit.

1 Overview of the sector and scope

This chapter gives an overview of the fabricated metal products manufacturing sector and describes which companies and within companies, which activities and processes are covered in the scope of this report.

1.1 Composition of the fabricated metal products manufacturing sector

1.1.1 Relevant NACE codes

The industrial sector investigated in this report is the fabricated metal products manufacturing sector, except machinery and equipment. This sector is mostly covered by NACE Rev. 2 Division 25. The division 25 includes the manufacture of products made solely from metal (such as parts, containers and structures), usually with a static, immovable function; these can be contrasted with combinations or assemblies of such metal products (sometimes with other materials) into more complex units that — unless they are purely electrical, electronic or optical — work with moving parts and are classified to Divisions 26 to 30. The whole NACE division 25 is included in the scope of this report whereas it is composed of eight groups and further subdivided in classes.

NACE codes 25.5 (Forging, pressing, stamping and roll-forming of metal; powder metallurgy) and NACE code class 25.6 (Treatment and coating of metals; machining) focus on the core activities/processes of the fabricated metal products manufacturing sector. Almost all fabricated metal products manufacturing companies use one or more of these activities in their production process. The other NACE code classes (25.1 till 25.4 and 25.7 and 25.9) describe typical products made in the fabricated metal products manufacturing sector.

NACE Code Division 24 ("Manufacture of basic metals") refers broadly to the manufacture of the basic metals. In particular, the NACE code class 24.10 ("Manufacture of basic iron and steel and of ferro-alloys") deals with the primary manufacturing activities of iron and steel and thus is excluded from the scope of this report. The classes, 24.2 ("Manufacture of tubes, pipes, hollow profiles and related fittings, of steel") and 24.3 ("Manufacture of other products of first processing of steel") are included in the scope of the report. Likewise, NACE code class 24.5 "Casting of metals") are included in the scope, since it deals with processes relevant for the fabricated metal products sector. However, for NACE code classes 24.2, 24.3 and 24.5, the scope of this report refers only to small scale operations, those which are not covered under the Industrial Emissions Directive[7] (IED).

This report refers also to manufacturing processes that are not only employed by companies from the fabricated metal products manufacturing sector, but also by other sectors. This applies specifically to NACE Code Division 28 ("Manufacture of machinery and equipment n.e.c."), which covers diverse sectors from the manufacturing of specific metal products e.g. bearings, to manufacture of plastic and rubber machinery. A selection of the most relevant NACE code classes was made and the NACE Code classes 28.14 ("Manufacture of other taps and valves") and 28.15 ("Manufacture of bearings, gears, gearing and driving elements") have been included in the scope of this report. Regarding the activities that fall under NACE Code Division 29 ("Manufacture of motor vehicles, trailers and semi-trailers"), only the NACE code class 29.32 ("Manufacture of other parts and accessories for motor vehicles") is included to the extent that the products concerned are composed mainly of metal. The same rule,

[7] Further information on the IED can be found available online: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32010L0075

applies to the NACE code classes 32.12 ("Manufacture of jewellery and related articles"), 32.13 ("Manufacture of imitation jewellery and related articles") and 32.20-32.50 (covering manufacture of musical instruments, sports good, games and toys and manufacture of medical and dental instruments and supplies). Table 1.1 presents all the activities that are included in the scope of this report.

Table 1.1. Overview of the Section C - Manufacturing NACE divisions, groups and classes, included in the scope of the report

NACE Division	NACE code group	NACE code class	Description
24	**Manufacture of basic metals**		
	24.2		Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
		24.20*	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
	24.3		Manufacture of other products of first processing of steel
		24.31*	Cold drawing of bars
		24.32*	Cold rolling of narrow strip
		24.33*	Cold forming or folding
		24.34*	Cold drawing of wire
	24.5		Casting of metals
		24.51*	Casting of iron
		24.52*	Casting of steel
		24.53*	Casting of light metals
		24.54*	Casting of other non-ferrous metals
**: only small scale operations (considerably smaller than IED thresholds with substantially different manufacturing processes, e.g. much more manual than automated processes)*			
25	**Manufacture of fabricated metal products, except machinery and equipment**		
	25.1		Manufacture of structural metal products
		25.11	Manufacture of metal structures and parts of structures
		25.12	Manufacture of doors and windows of metal
	25.2		Manufacture of tanks, reservoirs and containers of metal
		25.21	Manufacture of central heating radiators and boilers
		25.29	Manufacture of other tanks, reservoirs and containers of metal
	25.3		Manufacture of steam generators, except central heating hot water boilers
		25.30	Manufacture of steam generators, except central heating hot water boilers
	25.4		Manufacture of weapons and ammunition
		25.40	Manufacture of weapons and ammunition
	25.5		Forging, pressing, stamping and roll-forming of metal; powder metallurgy
		25.50	Forging, pressing, stamping and roll-forming of metal; powder metallurgy
	25.6		Treatment and coating of metals; machining

NACE Division	NACE code group	NACE code class	Description
		25.61	Treatment and coating of metals
		25.62	Machining
	25.7		Manufacture of cutlery, tools and general hardware
		25.71	Manufacture of cutlery
		25.72	Manufacture of locks and hinges
		25.73	Manufacture of tools
	25.9		Manufacture of other fabricated metal products
		25.91	Manufacture of steel drums and similar containers
		25.92	Manufacture of light metal packaging
		25.93	Manufacture of wire products, chain and springs
		25.94	Manufacture of fasteners and screw machine products
		25.99	Manufacture of other fabricated metal products n.e.c.
28	**Manufacture of machinery and equipment n.e.c.**		
	28.1		Manufacture of general — purpose machinery
		28.14**	Manufacture of other taps and valves
		28.15**	Manufacture of bearings, gears, gearing and driving elements
29	**Manufacture of motor vehicles, trailers and semi-trailers**		
		29.32**	Manufacture of other parts and accessories for motor vehicles
32	**Other manufacturing**		
	32.1		Manufacture of jewellery, bijouterie and related articles
		32.12**	Manufacture of jewellery and related articles
		32.13**	Manufacture of imitation jewellery and related articles
	32.2		Manufacture of musical instruments
		32.20**	Manufacture of musical instruments
	32.3		Manufacture of sports goods
		32.30**	Manufacture of sports goods
	32.4		Manufacture of games and toys
		32.40**	Manufacture of games and toys
	32.5		Manufacture of medical and dental instruments and supplies
		32.50**	Manufacture of medical and dental instruments and supplies
33	**Repair and installation of machinery and equipment**		
	33.1		Repair of fabricated metal products, machinery and equipment
		33.11	Repair of fabricated metal products
		33.12**	Repair of machinery

** these activities are considered in scope insofar as the products concerned are composed mainly of metal

1.1.2 Number and size of fabricated metal products manufacturing enterprises

The fabricated metal products manufacturing sector within the EU-28 comprised 550 943 enterprises in 2011. This represents approximately 26% of the total number of enterprises of the manufacturing (Section C) NACE divisions. The data of 2011 are presented in this report. Although more recent data is available (i.e. 2013), the 2011 data appeared to be more complete throughout the various parameters analysed. Furthermore, the trends and distribution of data in 2011 does not significantly differ from the data of 2013.

Within NACE Division 24, the NACE group 24.5 "Casting of metals" has the highest number of enterprises (122 050 in 2011). As far as the NACE Division 28 is concerned, the two groups 28.14 and 28.15 have a similar number of registered enterprises (approximately 2 900 registrations). NACE group 32.50 (Manufacture of medical and dental instruments and supplies") has the largest number of enterprises (63 322) followed by the group 32.12 Manufacture of jewellery and related articles, 28 603. Likewise, registrations for NACE group 33.12 ("Repair of machinery") were in 2011 approximately 77 470 enterprises.

Within NACE Division 25, code groups "Treatment and coating of metals and machining" (Group 25.6) and "Manufacture of structural metal products" (Group 25.1) are the groups with the highest number of enterprises in the fabricated metal products manufacturing sector, followed by "Manufacture of cutlery, tools and general hardware" (Group 25.7) and "Manufacture of other fabricated metal products" (Group 25.9). The "Manufacture of steam generators" except central heating hot water boilers (Group 25.3) and "Manufacture of weapons and ammunition" (Group 25.4) have the smallest share in terms of number of enterprises. Table 1.2 presents the number of enterprises (reference year 2011) in all the different NACE code groups, covered in the scope of this report.

Table 1.2. Number of enterprises in the fabricated metal products manufacturing sector; breakdown based on the NACE Rev.2 groups covered in the scope of this report (Eurostat, 2011)

NACE Rev.2	Number of enterprises
Manufacture of other products of first processing of steel (Group 24.3)	2 944
Casting of metals (Group 24.5)	6 995
Manufacture of structural metal products (Group 25.1)	122 050
Manufacture of tanks, reservoirs and containers of metal (Group 25.2)	5 507
Manufacture of steam generators (Group 25.3)	1 017
Manufacture of weapons and ammunition (Group 25.4)	1 277
Forging, pressing, stamping and roll-forming of metal and powder metallurgy (Group 25.5)	15 000
Treatment and coating of metals and machining (Group 25.6)	142 879
Manufacture of cutlery, tools and general hardware (Group 25.7)	52 300
Manufacture of other fabricated metal products (Group 25.9)	51 000
Manufacture of other taps and valves (Group 28.14)	2 909
Manufacture of bearings, gears, gearing and driving elements (Group 28.15)	2 978
Manufacture of other parts and accessories for motor vehicles (Group 29.32)	8 786
Manufacture of jewellery and related articles (Group 32.12)	28 603
Manufacture of imitation jewellery and related articles (Group 32.13)	9 270

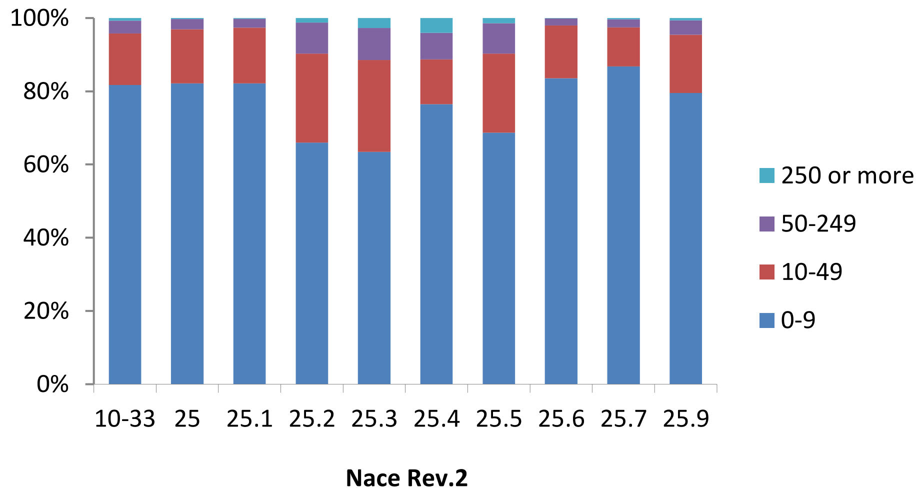
NACE Rev.2	Number of enterprises
Manufacture of musical instruments (Group 32.20)	5 000
Manufacture of sports goods (Group 32.30)	4 275
Manufacture of games and toys (Group 32.40)	5 043
Manufacture of medical and dental instruments and supplies (Group 32.50)	63 322
Repair of fabricated metal products (Group 33.11)	12 364
Repair of machinery (Group 33.12)	77 470

The fabricated metal products manufacturing sector is characterised by the large number of Small and Medium-sized Enterprises (SMEs). In the Eurostat structural business statistics, size classes are generally defined by the number of persons employed. The following division of size classes is used:

- (1) SMEs, with 1 to 249 persons employed:
    - (a) micro enterprises: with less than 10 persons employed;
    - (b) small enterprises: with 10 to 49 persons employed;
    - (c) medium-sized enterprises: with 50 to 249 persons employed;
- (2) Large enterprises, with 250 or more persons employed.

For instance, considering only the companies classified under NACE code 25, only 0.3% of the fabricated metal products manufacturing enterprises in the EU-28 are categorised as large enterprises (2011), while 82% of companies has less than 10 persons employed (Figure 1.1).

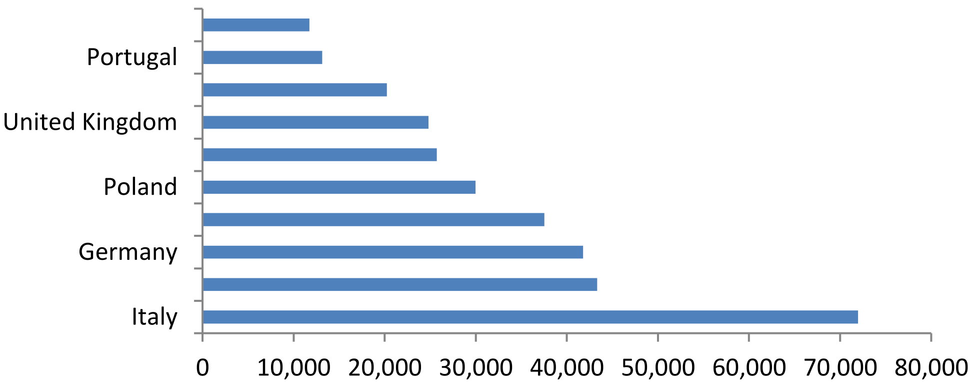
Figure 1.1. Share of enterprise size classes (by number of persons employed) of total manufacturing (Division C 10-33) and fabricated metal products manufacturing (Division 25 and groups) (Eurostat, 2011)



1.1.3 Geographical distribution

In the EU-28 (reference year 2011), Italy has the highest number of fabricated metal products manufacturing enterprises, followed by Czech Republic, Germany, Spain and Poland (Eurostat, 2011) (Figure 1.2).

Figure 1.2. The 10 countries with the highest number of fabricated metal products manufacturing enterprises (all NACE groups covered under the scope of this report) within the EU-28 (Eurostat, 2011)



1.2 Economic relevance of the fabricated metal products manufacturing sector

In 2011 the total turnover of the EU-28 of the NACE activities covered in the scope of the report accounted for 1 006 362 million euros representing approximately 14% of the turnover of total manufacturing (division 10-33). The relative share of turnover for all the different covered NACE activities in this report is presented in
Figure 1.3. Within NACE Division 25, the turnover significantly differs between the different NACE 25 groups, with the manufacture of structural metal products (Group 25.1) having the highest turnover (26%) followed by the treatment and coating of metals; machining (Group 25.6, 23%) and the manufacture of other fabricated metal products (Group 25.9, 20%) (Figure 1.4).

Figure 1.3. Relative share of turnover for all the NACE activities under the scope of this report (Eurostat, 2011)

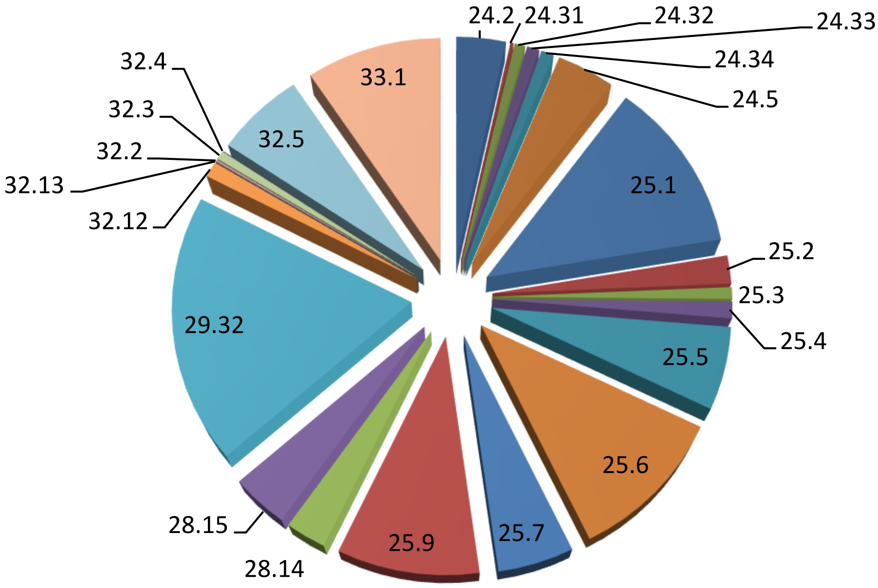
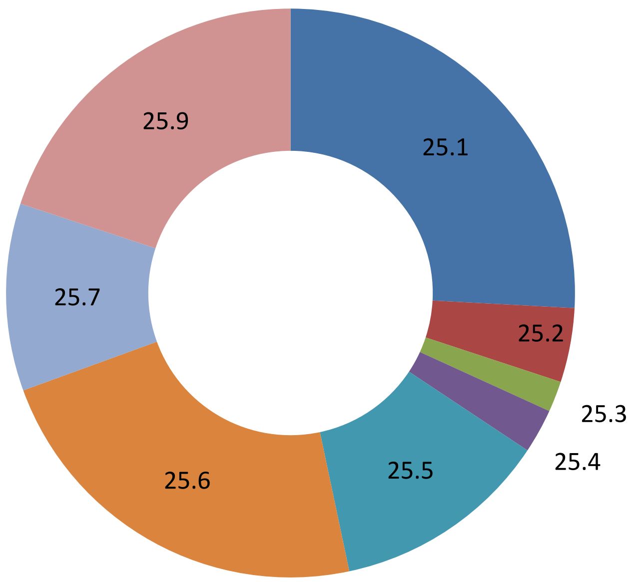


Figure 1.4. **Relative share of turnover for the NACE division 25 groups; total turnover equaled 472,000 million euros (Eurostat, 2011)**



Important economic indicators of the fabricated metal products manufacturing sector (turnover, added value at factor cost and the number of employees) and their distribution within the EU-28 are given in Table 1.3.

Table 1.3. **Economic indicators of the EU-28 fabricated metal products manufacturing sector (Eurostat, 2011)**

Region/country	Turn over	Share	Production value	Share	Value added at factor cost	Share
	million €	%	million €	%	million €	%
Czech Republic	13673.30	1.36%	13273.5	1.36%	4,062.3	1.26%
Estonia	1396.00	0.14%	1338.3	0.14%	352.8	0.11%
Netherlands	27958.00	2.78%	25502.9	2.62%	9,034.1	2.81%
Finland	9278.00	0.92%	9065.6	0.93%	3,280.7	1.02%
Switzerland	20380.60	2.03%	23539.1	2.41%	10,840.8	3.37%
Slovenia	5524.90	0.55%	4854.6	0.50%	1,497.6	0.47%
Hungary	12417.00	1.23%	11300.5	1.16%	2,967.5	0.92%
Ireland	12299.40	1.22%	12079.6	1.24%	5,323.1	1.65%
Norway	10021.50	1.00%	9438.8	0.97%	3,496.2	1.09%
Croatia	2070.00	0.21%	1916.3	0.20%	734.2	0.23%
Portugal	11524.40	1.15%	11170.7	1.15%	3,117.4	0.97%
Denmark	11033.40	1.10%	10739.5	1.10%	3,932.4	1.22%
Slovakia	12039.00	1.20%	11589.2	1.19%	2,840.3	0.88%
Belgium	24442.70	2.43%	23254.2	2.38%	6,218.6	1.93%
Greece	6037.10	0.60%	5708.7	0.59%	2,157.8	0.67%
Romania	9194.50	0.91%	8708	0.89%	1,811.8	0.56%

Region/country	Turn over	Share	Production value	Share	Value added at factor cost	Share
Poland	41344.90	4.11%	38427.5	3.94%	11,617.0	3.61%
Austria	25146.00	2.50%	24067	2.47%	8,904.7	2.77%
Spain	63583.40	6.32%	62599.6	6.42%	19,782.9	6.15%
Sweden	30317.20	3.01%	29169	2.99%	9,853.2	3.06%
United Kingdom	73148.30	7.27%	68418.8	7.02%	28,719.1	8.93%
France	113762.80	11.30%	101135.5	10.37%	35,168.4	10.93%
Germany	306532.30	30.46%	293211.7	30.07%	103,800.1	32.27%
Italy	159114.90	15.81%	159460.6	16.35%	46,322.1	14.40%
EU 28	1006360.50		975185.1		321,654.1	

1.3 Main environmental aspects and pressures of the fabricated metal products manufacturing sector

1.3.1 Environmental aspects

The fabricated metal products manufacturing sector can be characterised by its main environmental aspects and pressures. According to the EMAS regulation (1221/2009) an environmental aspect is an element of an organisation's activities, products or services that has or can have an impact on the environment. The environmental aspects of a company are then linked to an environmental pressure, e.g. emissions to air or water, production of waste, use of raw materials, etc. In this context a distinction can be made between direct and indirect environmental aspects:

- '*Direct environmental aspect'* means an environmental aspect associated with activities, products and services of the organisation itself over which it has direct management control;
- '*Indirect environmental aspect'* means an environmental aspect which can result from the interaction of a company with third parties and which can to a reasonable degree be influenced by a company.

In this section the main environmental aspects and pressures of the entire fabricated metal product manufacturing sector in the EU-28 are described. The type of processes applied does not significantly differ depending on the fabricated metal product manufacturing subsectors. Similar processes and activities are used in the entire fabricated metal product manufacturing sector, like logistics, utilities, and manufacturing processes (removing, shaping, joining, and treatment). There are no clear indications of important differences between the fabricated metal product manufacturing subsectors in terms of processes and activities. Therefore, the analysis of environmental aspects and pressures is performed for the processes and activities applied in the fabricated metal product manufacturing sector as a whole.

An overview of the direct and indirect environmental aspects and pressures in the fabricated metal product manufacturing sector is presented in Figure 1.5. The **direct environmental aspects** of the fabricated metal product manufacturing sector are mainly related to:

- Product and manufacturing design
    - Product design
    - Infrastructure design (plant level)

  - Process design (plant level)
- Manufacturing processes:
  - Casting processes
  - Shaping processes
  - Metal powder processes
  - Heat treatment processes
  - Removing processes
  - Additive processes
  - Deformation processes
  - Joining processes
  - Surface treatment
  - Assembly
- Supporting processes:
  - Management, procurement, supply chain management and quality control
  - Logistics handling, storage, packaging
  - Utilities and maintenance
  - Emissions treatment

The **indirect environmental aspects**, which can be reduced by the fabricated metal product manufacturing sector upstream and downstream in the value chain, are mainly related to:

- Upstream activities:
  - Raw material extraction and primary metal production
  - Tools and equipment production
- Downstream activities:
  - End of life
  - Use and service phase (e.g. disassembly)
  - Waste management

Figure 1.5. Overview of the direct and indirect environmental aspects of the fabricated metal product manufacturing sector

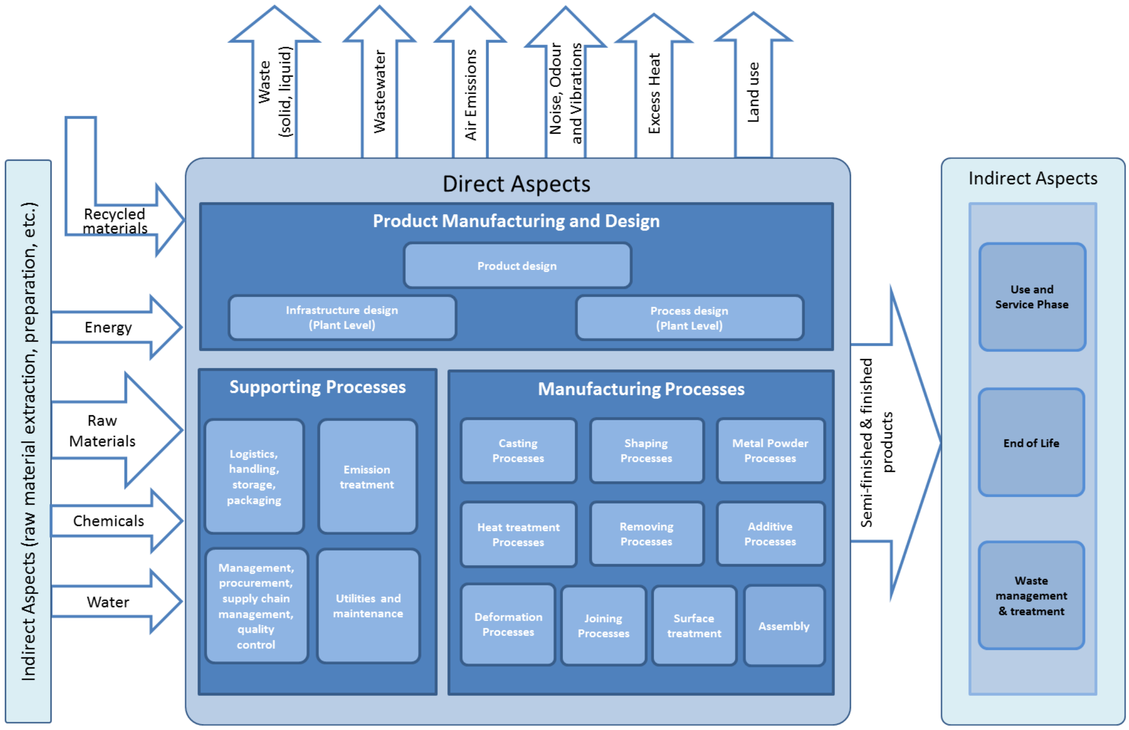


Figure 1.5 gives an indication of the main environmental pressures related to the direct and indirect environmental aspects. However, a more detailed overview and assessment of the environmental pressures is given in the section 1.3.2 of this report.

1.3.2 Environmental pressures and impacts

Table 1.4 and Table 1.5 list the direct and indirect environmental aspects and pressures for companies of the fabricated metal products manufacturing sector. The environmental pressures are typically related to:

- Raw materials
- Energy
- Water
- Consumables
- Biodiversity
- Emissions to:
  - Water
  - Air
- Noise, odour, vibration etc.,
- Waste:
  - Non-hazardous waste
  - Hazardous waste

The interaction between the fabricated metal products manufacturing sector and the upstream activities has mainly an influence on the resource use, especially the use of raw materials, energy and consumables and on the production of (non-hazardous) waste. As for the downstream activities, the interaction has mainly an influence on the use of energy and the production of non-hazardous waste.

The assessment of the environmental pressures of the activities itself, i.e. without considering the interaction between up- and downstream activities, is presented in Table 1.4, for the direct aspects (fabricated metal products manufacturing sector) and the interface processes of the indirect aspects. The same categories of environmental pressures are used as in Table 1.5 (indirect aspects).

Table 1.4. **Most relevant direct environmental aspects and related environmental pressures**

Processes	Most relevant direct environmental aspects	Related main environmental pressures
Supporting processes	Management, procurement, supply chain management, quality control	Raw materials Energy Water Consumables Waste: non-hazardous
	Logistics handling, storage, packaging	Raw materials Energy Water Consumables Emissions to air Noise, odour, vibration etc. Land use Biodiversity Waste: non hazardous
	Emission treatment	Energy Consumables Emissions to water Emissions to air Noise, Odour, vibration etc. Waste: non-hazardous, hazardous
	Utilities and maintenance	Energy Water Consumables Emissions to water Noise, odour, vibration etc. Waste: non hazardous, hazardous Land use Biodiversity
Manuf acturin g proces	Casting	Raw materials Energy Waste: hazardous

Processes	Most relevant direct environmental aspects	Related main environmental pressures
	Shaping	Raw materials Energy Noise, odour, vibration etc. Waste: hazardous
	Metal powder	Raw materials Energy Noise, odour, vibration etc. Waste: hazardous
	Heat treatment	Raw materials Energy Noise, odour, vibration etc. Waste: hazardous
	Removing	Raw materials Energy Water Consumables Emissions to water Emissions to air Noise, odour, vibration etc. Waste: non-hazardous
	Additive	Raw materials Energy Noise, odour, vibration etc. Waste: hazardous, non hazardous
	Deformation	Raw materials Energy Noise, odour, vibration etc. Waste: hazardous
	Joining	Raw materials Energy Consumables Emissions to air Noise, odour, vibration etc. Waste: non-hazardous
	Surface treatment	Raw materials Energy Water Consumables Emissions to water Emissions to air Noise, odour, vibration etc. Waste: non-hazardous, hazardous
	Assembly	Energy Consumables

Processes	Most relevant direct environmental aspects	Related main environmental pressures
		Noise, odour, vibration etc. Waste: hazardous
Product and infrastructure design	Product design	Raw materials Energy Water Consumables Emissions to air
	Infrastructure design (plant level)	Raw materials Energy Water Consumables Emissions to air Emissions to water Waste: non-hazardous Land use Biodiversity
	Process design (plant level)	Raw materials Energy Water Consumables Emissions to air Emissions to water Waste: hazardous, non-hazardous

Table 1.5. Most relevant indirect environmental aspects and related environmental pressures

Processes /Activities	Most relevant indirect environmental aspects	Related main environmental pressures
Design processes (Upstream activities)	Raw material extraction and metal production	Raw materials Energy Water Consumables Emissions to water Emissions to air
	Tools and equipment production	
Manufacturing processes (Downstream activities)	Use and service phase	Raw materials Energy Consumables Emissions to air Waste: hazardous, non-hazardous
	End of Life	
	Waste management	

In the next paragraphs, some background information about the most relevant applied processes in the fabricated metal products manufacturing companies is given. In particular, this text analyses in some more detail the information highlighted in Figure 1.5 and goes deeper into the specificities and characteristics of each process.

Within the **design processes** the most important environmental pressures are related to the use of raw materials, energy and consumables. For example, companies having an impact on the product design can significantly reduce the environmental impact per manufactured product by material and process selection, product design optimisation for manufacturing processes etc. Some subsectors can currently have less freedom in process selection compared to other subsectors, e.g. manufacturing of wire products, forging, pressing, stamping and roll-forming of metal, powder metallurgy. Those sectors are defined based on the processes. Specific products can often be strongly linked to the production process, e.g. hot milling of I-beams (in subsector 'manufacturing of metal structures and part of structures').

Logistics, handling, storage, packaging are not considered as main environmental aspect. The impact of these activities or services strongly depends on the product volume and on the product sensitivity to damage, e.g. by corrosion or surface damage. Important factors affecting the impact of handling and storage of products are temperature, shelf life, hazardous material storage requirements (consumables), inside or outside storage possibilities, etc. Logistics is either organised and managed by the company itself, by the suppliers or outsourced to a private logistic organisation. Additionally, packaging ensures the quality of the products, e.g. protecting against corrosion at storage and transport. Packaging processes mainly have an impact on the use of raw materials (packaging materials) and the production of non-hazardous waste streams.

The management and **treatment** of water and air **emissions** and of hazardous residues require considerable amount of energy. These activities usually lead to important emissions of discharged water and non-hazardous waste.

The **utilities and maintenance** applied in the fabricated metal products manufacturing sector (e.g. heating, cooling, compressed air) can require significant energy use. Therefore, heat recovery and smart controls can have a high potential in the reduction of energy use. In general, closed (cooling or heating) systems have a lower impact compared to open systems. Furthermore, these processes can lead to considerable noise and/or vibrations. Likewise, when waste are not segregated (e.g. metal residues from processing) it cannot be achieved recovery and recycling at high quality grades. In general, the utility department is responsible for the maintenance and effective operation of the production plant.

Management, procurement, supply chain management and quality control are also considered as <u>supporting processes</u> to the fabricated metal products manufacturing activities in this report. Although these supporting processes themselves have in general very low impact on the environment, they can have a high potential in influencing the environmental impact of the fabricated metal products manufacturing activities, especially regarding resource use or waste generation. For example, the implementation of an efficient supply chain management system in a company in the fabricated metal products manufacturing sector will not require any resource use or produce any waste, however, this system can lead to a reduction in resource use in the fabricated metal products manufacturing activities by efficiently managing (e.g. on time, demand) the resource supply. Similarly, the implementation of an efficient quality control system does not produce any emissions, but it can lead to a reduction in emissions or waste generation in the fabricated metal products manufacturing activities by improving process steps.

As part of the <u>manufacturing processes</u> of the fabricated metal products manufacturing sector, the **casting, shaping, metal powder additive, heat treatment and deformation processes** make large use of raw materials (ferrous and non-ferrous metals), consumables and energy. Noise and/or vibrations, air emissions and waste (typically non-hazardous) are the main environmental pressures related to these aspects. The energy used is mainly electricity whereas for thermal processes usually gas is applied.

Several **removing processes** are widely applied throughout all fabricated metal products manufacturing subsectors, e.g. drilling, turning, milling. Other processes are more related to one or more specific subsectors. EDM (Electrical Discharge Machining) processes are for example used in subsectors making products with high added value and precision (ammunition, other products etc.). Cutting, punching and laser cutting are applied in the fabrication of sheet metal and tubing. Most removing processes however, are characterised by a high impact on raw material and (electric) energy use. Almost all removed material consists of non-value added material. Consumables (such as cooling and lubricating consumables) are widely used in the entire fabricated metal products manufacturing sector. The nature of the processes generate non-hazardous waste (e.g. chips, turning, cut outs) containing a small amount of consumables (mainly coolant and/or lubrication).

Thermal **joining processes**, mainly welding and brazing, are generally applied in most fabricated metal products manufacturing subsectors except for manufacturing of wire products, forging, pressing, stamping and roll-forming of metal; powder metallurgy, fasteners and screws. Other joining processes, such as gluing and pressing are more specific and primarily applied for high end products. Apart from the use of energy and consumables (e.g. welding electrodes, shielding gases, glues), these processes can lead to air emissions (e.g. abrasive dust) and emissions of odour.

The **surface treatment processes** e.g. coating applications and post metallurgical treatment processes applied in the fabricated metal products manufacturing sector can differ between the various subsectors, depending on the products and applications. Heat treatment processes for example, differ largely for ferrous and non-ferrous metals (e.g. hardening and extrusion). Laser processes like engraving and polishing are used for specific high value products. Electrochemical surface treatment, have a high impact on water consumption since water based solutions are used in these processes. The waste water from those processes furthermore contains significant amounts of contaminants, due to the several process steps requiring a large set of chemicals and additives. Next to the contaminated waste water, hazardous waste and liquid waste streams are generated (e.g. (heavy) metals, organic compounds).

Assembly processes in the fabricated metal products manufacturing sector have to ensure the quality of the semi-finished or finished products. These processes make use of consumables and energy whereas contribute to the generation of noise, dust and vibrations, and waste (non-hazardous).

The concept and benefits for improving the environmental performance of fabricated metal products manufacturing companies are described under the chapters 2-4 of this report.

In order to understand and further analyse and monitor the direct and indirect environmental impacts of the sector, the activities classified under NACE Division 25 were compared against the classification system of an environmentally extended multi-regional input-output database including highly-detailed national input-output tables, the EORA database[8].

This database (EORA) is used to derive direct, indirect and total coefficients. Although EORA uses a slightly different sector classification system than NACE Rev. 2 (Table

[8] Link: www.worldmrio.com

1.6), which implies imperfect sectoral data matches, it still offers valuable information on coefficients for the comparison of the subsectors. An input-output analysis allows to consistently mapping both the direct and indirect effects of supplies to the sector. Direct effects are triggered by the supplies to the sector; indirect effects take into account the complete value chain perspective of these deliveries (upstream activities); total effects consider both the direct and indirect effects. An input-output analysis allows expressing the socio-economic impact and related environmental impact in direct, indirect and total coefficients. This provides key numbers which immediately can be used analytically.

Table 1.6. **Comparison of sector classification systems of EORA (UK) and NACE Rev.2 (NACE Division 25)**

EORA classification (UK)	*NACE Rev.2*
Manufacture of metal structures and parts of structures	25.11
Manufacture of builders' carpentry and joinery of metal	25.12
Manufacture of central heating radiators and boilers	25.21
Manufacture of tanks, reservoirs and containers of metal	25.29
Manufacture of steam generators, except central heating hot water boilers	25.30
Manufacture of weapons and ammunition	25.40
Forging, pressing, stamping and roll forming of metal; powder metallurgy	25.50
Treatment and coating of metals	25.61
General mechanical engineering	25.62
Manufacture of cutlery	25.71
Manufacture of locks and hinges	25.72
Manufacture of tools	25.73
Manufacture of steel drums and similar containers	25.91
Manufacture of light metal packaging	25.92
Manufacture of wire products	25.93
Manufacture of fasteners, screw machine products, chains and springs	25.94
Manufacture of other fabricated metal products not elsewhere classified	25.99

Some environmental parameters can be derived from the Eurostat database for the entire fabricated metal products manufacturing sector (for companies under NACE Division 25), e.g. direct emissions of NMVOC and CO_2. In order to calculate the (direct and indirect) impacts of the individual subsectors, the coefficients from the EORA (UK) database can be used. These calculations however mainly give an indication of the relative importance of the individual subsectors related to a specific environmental parameter, given the constraints of using highly-detailed national input-output tables.

Table 1.7 presents an overview of the analysis based on the Eurostat and EORA (UK) database.

Table 1.7. **Direct and total emissions and resource use of the fabricated metal products manufacturing (sub) sectors (Eurostat and EORA, 2011)**

Parameter	*Source*	*10-33 (manufacturing) - tonnes*	*C 25 - tonnes*	*Share of NACE 25 (%)*							
				25.1	*25.2*	*25.3*	*25.4*	*25.5*	*25.6*	*25.7*	*25.9*
Direct emissions – NMVOC	Eurostat	2.381.421	207.173								
Direct emissions – CO_2	Eurostat	884.086.665	15.040.502								
Direct emissions - total GHG (CO_2-eq.)	EORA			27	4	2	3	12	20	10	22
Total emissions - total GHG (CO_2-eq.)	EORA			29	4	2	2	11	20	9	23
Direct emissions - air quality NMVOC	EORA			12	10	4	2	9	13	15	34
Total emissions -air quality NMVOC	EORA			23	8	3	3	10	17	12	25
Direct use - total water	EORA			28	4	2	3	12	20	11	21
Total use - total water	EORA			29	5	2	3	10	18	9	23
Direct use - energy	EORA			26	4	2	3	12	20	10	23
Total use - energy	EORA			29	4	2	2	11	21	8	23

Based on the analysis in Table 1.7, the indirect emissions of the fabricated metal products manufacturing sector can be calculated. Figure 1.6 presents the relative importance of both the direct and indirect emissions of NMVOC (non-methane volatile organic compounds), GHG (greenhouse gas) emissions, energy use and water use. Since the data in EORA (UK) for material use are not complete, this parameter is not calculated.

Figure 1.6. Relative share of direct and indirect emissions of the fabricated metal products manufacturing sector (EORA, 2011)

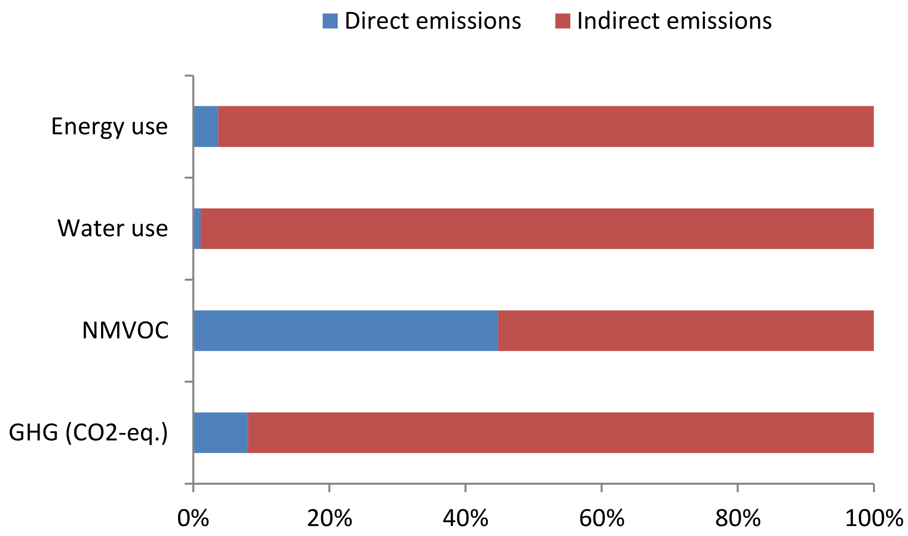


Figure 1.6 indicates that the relative share of direct and indirect emissions can significantly differ depending on the environmental parameter. Ca. 45% of the NMVOC emissions in the value chain originate from the fabricated metal products manufacturing sector (NACE Division 25), while for water use, energy use and GHG emissions this share of direct emissions is ca. 1, 4 and 8%, respectively. The largest part of these indirect emissions originates from upstream activities like raw materials production requiring significant amounts of energy and water and producing GHG emissions.

The Shankey diagrams in Figure 1.7 and Figure 1.8 give an overview of the material flows of steel and aluminium respectively. The fabricated metal products manufacturing sector (including rolling/forming and fabrication stage) uses metals from founding industry to produce semi-finished products and finished-products. Some examples are listed below:

- NACE C28: Manufacture of machinery and equipment n.e.c.; e.g.: NACE 28.1: Manufacture of engines and turbines, except aircraft, vehicle and cycle engines; NACE 28.1.1: Manufacture of engines and turbines, except aircraft, vehicle and cycle engines;
- NACE 29.2: Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers (NACE 29.2);
- NACE 29.3: Manufacture of parts and accessories for motor vehicles;
- NACE 30.1: Building of ships and boats;
- NACE 31: Manufacture of furniture;
- NACE 32: Other manufacturing.

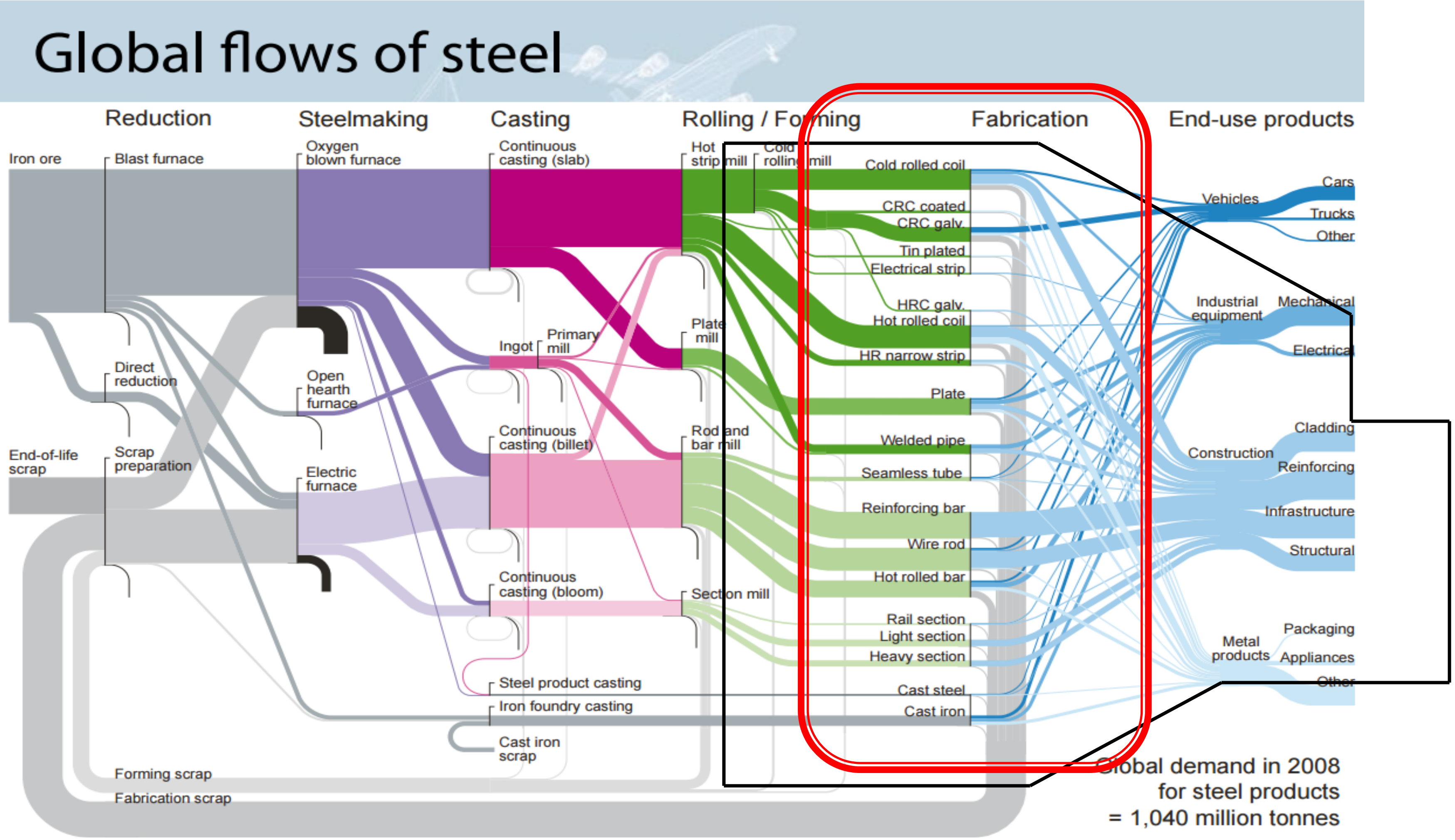


Figure 1.7. **Basis: Shankey diagram of steel flow – the activities of the fabricated metal products manufacturing sector are situated in the green area (Rolling and forming process) (Allwood, 2011); black line: NACE activities covered in the scope of the report; double red line: scope of this report**

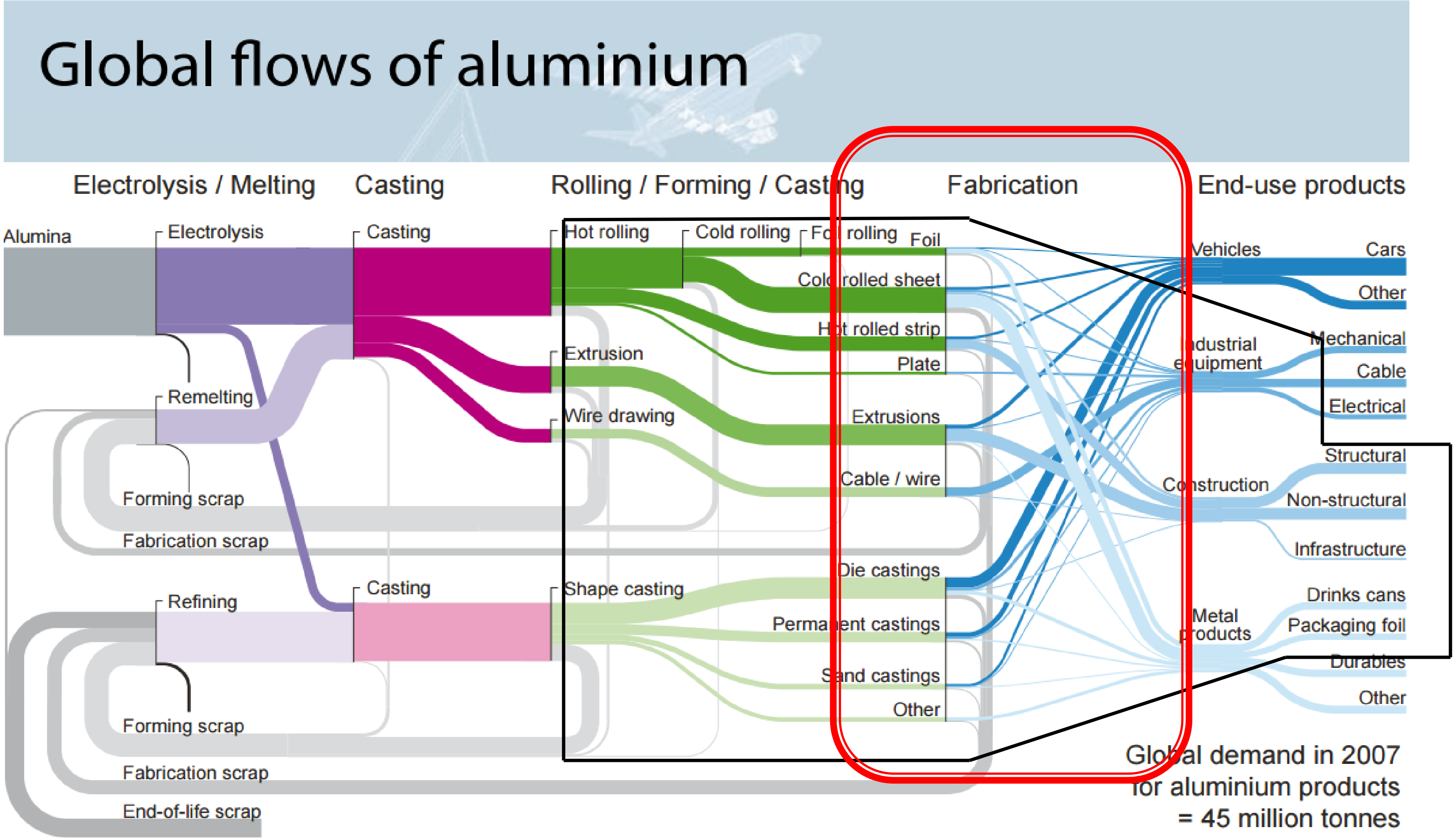


Figure 1.8. Basis: Shankey diagram of aluminium flow – the activities of the fabricated metal products manufacturing sector are situated in the green area (Rolling and forming process). (Allwood, 2011) black line: NACE activities covered in the scope of the report); double red line: scope of this report

1.4 EMAS and the fabricated metal products manufacturing sector

In the EU-28 there was a total of 95 companies in the fabricated metal products manufacturing sector (NACE Division 25) having an EMAS registration in 2017. Since some of these companies had an EMAS registration number for more than one NACE Division 25 group, the total number of EMAS registrations in the EU-28 in the fabricated metal products manufacturing sectors equalled 327 (Table 1.8) in 2017. The Manufacture of other parts and accessories for motor vehicles (NACE 29.32) was the class with the highest number of EMAS registrations, followed by the treatment and coating of metals (NACE 25.61). In Germany, there was 175 EMAS registrations followed by Italy where 40 EMAS registered organisations were located in 2017. These two countries had the highest numbers compared to other EU-28 member states.

Table 1.8. **Overview of EMAS registrations in EU-28 in the fabricated metal products manufacturing sector for the NACE activities covered in the scope of this report in 2017** (http://ec.europa.eu/environment/emas/register/)[9]

NACE code	AT	BG	CZ	DE	DK	ES	GR	HU	IT	PL	PT	RO	SE	UK	Total
24.20	1					1			1					1	4
24.31				4											4
24.32				4					1						5
24.33				5											5
24.51	1		1	6		2			3						13
24.52	1			2					1						4
24.53				4		2			1						7
24.54				4		1									5
25.11	1	1	4	4		2		2	7		2	1		1	25
25.12			2	3		2			2		1				10
25.21				3		1									4
25.29				3		1			1						5
25.30				3						1					4
25.40				3											3
25.50			1	4		1	1		2						9
25.61	1		1	8	1	4			21		1				37
25.62				6		2		1	6						15
25.71				3							1				4
25.72			1	3											4
25.73	1		1	4											6
25.91				4									1		5
25.92				5			1		2				1		9
25.93	1			4		1			2				1		9

[9] As some data in the EU EMAS register are out of date or have expired, a substantial update of the system is presently underway. Current figures may not reflect the true number of organisations and sites in EU Member States. This may take a few weeks to be completed (see disclaimer at http://ec.europa.eu/environment/emas/register/, last accessed on 30/10/2017).

NACE code	***AT***	***BG***	***CZ***	***DE***	***DK***	***ES***	***GR***	***HU***	***IT***	***PL***	***PT***	***RO***	***SE***	***UK***	***Total***
25.94	1			5									1		7
25.99	1			6		1	1		5				1		15
28.14	1			11					1				1		14
28.15				10					1				1		12
29.32	*2*		*1*	*47*		*7*			*1*		*3*				***61***
32.30				1											1
32.50				3		1			1						5
33.11				1					2	1					4
33.12		1		2		2			5	1	1				12
Total	**12**	**2**	**12**	**175**	**1**	**31**	**3**	**3**	**66**	**3**	**9**	**1**	**7**	**2**	**327**

1.5 EU legislation, policy instruments and best practice guidance

Processes and environmental aspects of the NACE Division 25 and NACE code classes 24.2, 24.3, 24.5, 28.14, 28.15, 29.32, 32.12, 32.13, 32.2, 32.3, 32.4, 32.5, 33.11 and 33.12 that are covered by one of the BRefs, directly or indirectly linked to the manufacture of fabricated metal products manufacturing as well as by EU legislation, policy instruments and best practice guidance are excluded from the scope of this report. However, the reader can find specific examples on how examples of BATs are relevant for companies and organisations from the fabricated metal products manufacturing sector (Section 2.7).

IED and BRefs

The Industrial Emissions Directive (IED) (Directive 2010/75/EU) is an integration (and revision) of the IPPC Directive (2008/1/EC) with the Large Plant Combustion Directive (2001/80/EC), the Waste Incineration Directive (2000/76/EC), the Solvent Directive (1999/13/EC) and three Directives for the titanium dioxide industry (78/176/EEC - 82/883/EEC - 92/112/EEC). The IED obligates the EU member states to prevent, reduce and as far as possible eliminate pollution arising from industrial activities. The IED entered into force 6 January 2011 and concerns all installations where one or more of the activities included in annex I of the directive. In order to ensure the prevention and control of pollution, each installation should operate only if it holds a permit or, in the case of certain installations and activities using organic solvents, only if it holds a permit or is registered. The permit should include all the measures necessary to achieve a high level of protection of the environment as a whole and to ensure that the installation is operated in accordance with the general principles governing the basic obligations of the operator. The permit should also include emission limit values for polluting substances, or equivalent parameters or technical measures, appropriate requirements to protect the soil and groundwater and monitoring requirements. Permit conditions should be set on the basis of best available techniques.

In order to determine best available techniques and to limit imbalances in the Union as regards the level of emissions from industrial activities, reference documents for best available techniques (BAT reference documents) are drawn up. BRefs are sectoral reference reports and give an overview of what BAT are and which environmental performances can be achieved with BAT.

BEMP 2.7 (Link to the BREF relevant for fabricated metal product manufacturing companies) presents the relevant BRefs that enable companies from the fabricated metal products manufacturing sector to optimise their environmental performance of their processes and operations.

1.6 Conclusion of the scope

Based on the analysis carried out in the previous sections, the scope of this report is summarised in the following paragraphs.

This report addresses the environmental performance of the Fabricated Metal Products manufacturing sector. The target group of this document are companies belonging to the Fabricated Metal Products manufacturing sector, and specifically companies belonging to the following NACE codes (according to the statistical classification of economic activities established by Regulation (EC) No 1893/2006[10]):

- NACE Division 24* "Manufacture of basic metals"
  - 24.2 Manufacture of tubes, pipes, hollow profiles and related fittings, of steel (24.20)
  - 24.3 Manufacture of other products of first processing of steel (24.31 - 24.34)
  - 24.5 Casting of metals (24.51 – 24.54)
- NACE Division 25 "Manufacture of fabricated metal products, except machinery and equipment" (included all activities)
- NACE Division 28** "Manufacture of machinery and equipment n.e.c."
  - 28.1 Manufacture of general – purpose machinery (including only 28.14 and 28.15)
- NACE Division 29** "Manufacture of motor vehicles, trailers and semi-trailers"
  - 29.3 Manufacture of other parts and accessories for motor vehicles (29.32)
- NACE Division 32** "Other manufacturing"
  - 32.1 Manufacture of jewellery, bijouterie and related articles (32.11-32.13)
  - 32.2 Manufacture of musical instruments (32.20)
  - 32.3 Manufacture of sports goods (32.30)
  - 32.4 Manufacture of games and toys (32.40)
  - 32.5 Manufacture of medical and dental instruments and supplies (32.50)
- NACE Division 33 "Repair and installation of machinery and equipment"
  - 33.2 Repair of fabricated metal products, machinery and equipment (33.11 - 33.12**)

[10] Regulation (EC) No 1893/2006 of the European Parliament and of the Council of 20 December 2006 establishing the statistical classification of economic activities NACE Revision 2 and amending Council Regulation (EEC) No 3037/90 as well as certain EC Regulations on specific statistical domains (OJ L 393, 30.12.2006, p. 1).

* Only small scale operations (considerably smaller than IED thresholds with substantially different manufacturing processes, e.g. much more manual than automated processes).

** These activities are considered in scope insofar as the products concerned are composed mainly of metal.

The BEMPs of this report are divided into three main chapters (Table 1.9) which cover, from the perspective of the manufacturers, the main environmental aspects of the fabricated metal products manufacturing companies.

Table 1.9: Structure of the BEMPs of the report for the fabricated metal products manufacturing sector and main environmental aspects addressed

Chapter	Description	Main environmental aspects addressed
2. BEMPs for the cross-cutting issues	BEMPs that provide guidance on how manufacturers can integrate environmental sustainability frameworks into their existing business models and management systems in order to reduce their environmental impacts.	Site management
3. BEMPs for the optimisation of utilities	BEMPs that provide guidance on how to improve the overall environmental performance of the supporting processes of the manufacturing plants, such as lighting or ventilation.	Utilities and maintenance
4. BEMPs for the manufacturing processes	BEMPs that improve the environmental performance of the core manufacturing operations.	Industrial processes

The direct and indirect environmental aspects presented in Table 1.10 and Table 1.11 respectively, were selected as the most commonly relevant in the sector. However, the environmental aspects to be managed by specific companies need to be assessed on a case-by-case basis.

Table 1.10: Most relevant direct environmental aspects and related main environmental pressures addressed in this report

Processes	Most relevant direct environmental aspects	Related main environmental pressures
Supporting processes	Management, procurement, supply chain management, quality control	Raw materials Energy Water Consumables Waste: non-hazardous
	Logistics handling, storage, packaging	Raw materials Energy Water Consumables Emissions to air Noise, odour, vibration etc. Land use Biodiversity Waste: non hazardous
	Emission treatment	Energy

Processes	**Most relevant direct environmental aspects**	**Related main environmental pressures**
		Consumables Emissions to water Emissions to air Noise, Odour, vibration etc. Waste: non-hazardous, hazardous
	Utilities and maintenance	Energy Water Consumables Emissions to water Noise, odour, vibration etc. Waste: non hazardous, hazardous Land use Biodiversity
Manufacturing processes	Casting	Raw materials Energy Waste: hazardous
	Shaping	Raw materials Energy Noise, odour, vibration etc. Waste: hazardous
	Metal powder	Raw materials Energy Noise, odour, vibration etc. Waste: hazardous
	Heat treatment	Raw materials Energy Noise, odour, vibration etc. Waste: hazardous
	Removing	Raw materials Energy Water Consumables Emissions to water Emissions to air Noise, odour, vibration etc. Waste: non-hazardous
	Additive processes	Raw materials Energy Noise, odour, vibration etc. Waste: hazardous, non hazardous
	Deformation	Raw materials Energy Noise, odour, vibration etc. Waste: hazardous
	Joining	Raw materials Energy Consumables Emissions to air Noise, odour, vibration etc. Waste: non-hazardous

Processes	Most relevant direct environmental aspects	Related main environmental pressures
	Surface treatment	Raw materials Energy Water Consumables Emissions to water Emissions to air Noise, odour, vibration etc. Waste: non-hazardous, hazardous
	Assembly	Energy Consumables Noise, odour, vibration etc. Waste: hazardous
Product and infrastructure design	Product design	Raw materials Energy Water Consumables Emissions to air
	Infrastructure design (plant level)	Raw materials Energy Water Consumables Emissions to air Emissions to water Waste: non-hazardous Land use Biodiversity
	Process design (plant level)	Raw materials Energy Water Consumables Emissions to air Emissions to water Waste: hazardous, non-hazardous

Table 1.11. Most relevant indirect environmental aspects and related environmental pressures

Activities	Most relevant indirect environmental aspects	Related main environmental pressures
Upstream	Raw material extraction and metal production	Raw materials Energy Water Consumables Emissions to water Emissions to air
	Tools and equipment production	
Downstream	Use and service phase	Raw materials Energy Consumables
	End of Life	

Activities	Most relevant indirect environmental aspects	Related main environmental pressures
	Waste management	Emissions to air Waste: hazardous, non-hazardous

The above listed environmental aspects are addressed directly by the individual BEMPs of this document (chapters 2, 3 and 4). Nevertheless, BEMP 2.7 (Link to the BREF relevant for fabricated metal product manufacturing companies) presents the relevant BRefs that enable companies from the fabricated metal products manufacturing sector to optimise their environmental performance of their processes and operations.
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2 Cross cutting measures

This chapter focusses on cross-cutting measures and practices, which can apply to all types of companies in the fabricated metal products manufacturing sector. In particular, the BEMPs of this chapter offer guidance on the devise, implementation and monitoring of different frameworks for environmental issues of the companies. These frameworks improve the overall environmental performance of the manufacturing companies and in parallel are useful for the companies to identify and eventually to optimise environmental impacts. In this chapter, the direct and indirect environmental impacts where fabricated metal products manufacturers have a considerable influence are covered.

Table 2.1 maps the identified BEMPs for the cross cutting chapter against the related environmental aspects and pressures, showing also the link to the relevant BREFs.

Table 2.1. Most relevant direct environmental aspects for the fabricated metal products manufacturing companies how these are addressed in the cross cutting chapter

BEMPs	Most relevant direct environmental aspects	Related main environmental pressures	Relevant BREFs
2.1 Applying effective methods for environmental management 2.2 Collaboration and communication along and across the value chain 2.3 Energy management 2.4 Environmentally and sound efficient management of chemicals 2.5 Biodiversity management 2.6 Remanufacturing and high-quality refurbishment of high value or large series products and components 2.7 Link to relevant Reference Documents on Best Available Techniques	Cross cutting operations of the manufacturing sites	Raw materials Energy Water Consumables Emissions to air Odour, noise and vibration Waste: Hazardous and non-hazardous waste Land use Biodiversity	ENE STM STS

2.1 Applying effective methods for environmental management

<table>
<tr><td colspan="6">SUMMARY OVERVIEW
BEMP is to use effective methods for environmental management, in order to optimise process and product design at the production stage and reduce environmental impacts along the whole value chain. This framework encompasses 2 levels:
• The strategic, with the envisioning such as circular economy and life cycle thinking approaches;
• The operational, with the use of tools that ensure continuous improvement of the environmental performance such as lean management and stock reduction.</td></tr>
<tr><td colspan="6">Relevant processes</td></tr>
<tr><td colspan="3">Cross cutting</td><td colspan="2">Optimisation of utilities</td><td>Manufacturing</td></tr>
<tr><td colspan="6">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td></tr>
<tr><td colspan="6">Environmental performance indicators</td></tr>
<tr><td colspan="6">- Resource efficiency (kg finished products / kg of material input (alternatively: kg waste produced / kg input materials in case the kg finished products are not known)
- Mapping of material flows and their environmental relevance (Y/N)
- On-site energy use (kWh / kg finished product or manufactured part[11])
- Scope 1, 2 and 3 CO2-emissions (kg CO2 equivalent / kg finished product or manufactured part)
- Water use (l water / kg finished product or manufactured part)</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="4">The BEMP is broadly applicable for all companies, including SMEs. Lack of sufficient in-house technical knowledge and the need for staff training can limit the applicability of this BEMP.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="4">Systematic consideration of life cycle thinking, lean management and circular economy in all strategic decisions making.
New products development are assessed for environmental improvements</td></tr>
<tr><td colspan="2">Related BEMPs</td><td colspan="4">2.2, 2.6</td></tr>
</table>

Description

Setting a clear environmental policy and a framework for environmental management is a key enabler to the systematic implementation of environmental improvement actions in any domain. This BEMP describes a set of environmental policy management principles and approaches and related environmental operational tools that companies can integrate into their management and/or organisational structure. This integration shall companies to optimise management and manufacturing processes and reduce environmental impacts along the whole value chain.

The measures of this BEMP go beyond the (mandatory) elements of an environmental management system e.g. EMAS. In fact, the implementation of EMAS (or another environmental management system) it is considered a preliminary step and it is thus not covered in this BEMP. Additionally, the BEMP does not aim to comprehensively describe in detail the mentioned approaches and tools but rather to provide an overview of their

[11] Remark for the functional unit in the denominator of the different indicators used to express the finished products: the output (expressed in the indicators as kg finished product of manufactured part), can be expressed in different ways: number of parts, kg of products etc. depending on the type of products and their homogeneity/heterogeneity. Companies can choose suitable metrics to express the output. The point is relevant across the different developed BEMPs of this report and will be made in a footnote.

concept. It actually explains the relation between them and shows how they can be actually integrated into the management strategy and companies' business models.

The content of this BEMP is divided into 2 levels:

1. The strategic, which includes the envisioning such as circular economy and life cycle thinking;

2. The operational, which outlines specific tools/actions/methods and how can be applied by the companies for the different value chain steps (e.g. supply chain management, product design) in order to achieve continuous improvement of the environmental performance. These tools can be stock reduction and lean management or other similar.

The information for these 2 levels is presented in Table 2.2 for each step of the value chain, as a source of inspiration for the companies of the sector. The suitability of those measures shall be analysed carefully and on a case-by-case basis by the companies' managers, taking into account the existing management practices and (local) environmental policies and regulations. Companies may implement some measures of this BEMP depending on their capacities, resources, ambition level and background with existing environmental and other management practices.

The implementation of most of the measures of this BEMP can affect the up- and downstream value chain. For instance, the concept of circular economy can trigger the communication and cooperation among different companies and business partners[12] and actually implement approaches such as industrial symbiosis or co-design etc.

[12] The communication and cooperation along and across the value chain is covered in detail in BEMP 2.2.

Table 2.2. Approaches for environmental management; target value chain phase and practical guidance for implementation

Approach	**Overview**	**Value chain steps**							**Actions/Tools/methods**[13]
		Supply chain management	Product design	Process design	Infrastructure and logistics	Manufacturing	Use	End of Life	**Examples of actions, tools or methods applied by fabricated metal products manufacturers to put in practice the different approaches**
Strategic level									
Circular economy	Resources are reused or recovered at their highest quality and kept circulating in the economy as long as possible	X	X	X	X	X	X	X	Material management based on mapping material flows Circular design or eco-design (e.g. innovation and stewardship) for new and existing products Development of skills for reverse cycles (e.g. refurbishing, logistics and warehousing) New business models (e.g. sale of a service or functionality instead of a product)

[13] This list is indicative and not exhaustive. The companies can implement other similar actions, methods and tools not listed hereby.

Approach	Overview	Value chain steps							Actions/Tools/methods[13]
Life cycle thinking	Mapping and consideration of environmental impacts throughout the product lifecycle	X	X	X	X	X	X	X	Systematic consideration of environmental impacts in all value chain steps (compulsory in EMAS, element of ISO 14001) LCA of products/processes (beyond EMAS) Carbon budget assessment (e.g. SBTi)
Operational level									
		Supply chain management	**Product design**	**Process design**	**Infrastructure and logistics**	**Manufacturing**	**Use**	**End of Life**	**Specific actions, tools or methods applied by fabricated metal products manufacturers to put in practice the different approaches**

Approach	**Overview**	**Value chain steps**							**Actions/Tools/methods**[13]
Operational efficiency	Seek, identify and reduce all types of waste or suboptimal practices in the organisation	(X)	(X)	X	X	X			Stock reduction Lean management Systematic consideration of environmental impacts in all value chain steps Carbon budget assessment (e.g. SBTi) Functional organisation of production Etc. Team management of production parts Cross-training of workers

Strategic level

Circular Economy

The transition to the circular economy implies a change in the companies' management strategy and business model. This change may affect product design stage and industrial manufacturing processes and can also contribute to the development of new business models (Heyes et al., 2018; Osterwalder and Pigneur, 2010).

Table 2.3 presents the elements of a circular economy approach that has been proposed and comprises three main stages and ten iterative steps (adapted from Heyes et al., 2018). This methodology can be used by all fabricated metal products manufacturers who wish to integrate circular economy into their management strategy and business models.

Specifically, the first three steps deal with the creation and definition of the company's vision within the circular economy, specifying for instance the constraints and the drivers etc. The next stage is to integrate that vision into the company's actual business model and to develop the corresponding pathways for the implementation of the future businesses/operations (steps 4 - 6). At the last steps, the company develops and implements the strategic action plans.

Table 2.3. The circular economy approach for a company (adapted from Heyes et al., 2018)

Stages	Steps
Envisioning	1. Create an overarching vision 2. Analyse drivers and constraints 3. Add specifics to vision
Designing	4. Characterise product/service portfolio 5. Product/service selection and evaluation 6. Propose product/service design and supply chain alternatives
Implementing	7. Evaluating alternatives 8. Devise scenarios and action plans 9. Validate scenarios and action plans 10. Implement and review

Overall, for fabricated metal products manufacturing companies, the shift from linear into circular business models involves designing and manufacturing of products in such a way as to reduce raw materials consumption, improve durability and energy efficiency, increase recyclability or the possibility to reuse end-of-life products. Specific examples of concrete actions that are based on the circular economy are the BEMPs 4.5 and 2.6 on, *Maintaining material value for metal residues* and *Remanufacturing and high quality refurbishment of high value of parts and products* respectively.

Life cycle thinking

Life cycle thinking implies considering all environmental impacts of metal fabrication from raw materials extraction to the end of life of fabricated metal products. Applying life cycle thinking enables companies to evaluate and manage trade-offs between impacts arising at different life cycle stages, understand where their major impacts are over the value chain, take responsibility for them and eventually reduce them.

When aiming at reducing the environmental impacts of fabricated metal products over the entire life cycle, new and innovative products or manufacturing processes need to be developed and designed, which may also require new ways of collaboration and organisational management.

A possible way to implement life cycle thinking is carrying out a complete life-cycle-assessment[14] or carbon footprint analysis of their whole operations and value chain and working actively to take responsibility and reduce the impact. In this context, Carbon Disclosure Project (CDP), an international organisation working together with companies to disclose their environmental information, together with partners such as World Wildlife Fund for nature (WWF), United Nations Global Compact (UNGC) etc. set up the Science Based Targets initiative (SBTi). This initiative developed sector specific methodologies to determine how much companies have to reduce their emissions to remain within the carbon budget. The initiative reviews targets set and submitted by companies, and publicly lists which targets have been 'accepted' (SBTi, 2017).

Operational level (operational efficiency)

In the next paragraphs, only lean management and stock reduction are presented. Nevertheless, manufacturers can use of similar methods/actions/tools, not mentioned hereby.

Lean management

The concept of lean management allows saving resources by improving processes and removing efficiencies and waste. Lean principles can be applied in companies of the sector to review and continuously improve the whole of their operations and, in particular, their manufacturing processes. The lean principles are used to detect inefficiencies or waste and put a focus on the delivered products and customer demands. The types of waste in a company can be of various natures and often are divided in seven categories (Lean manufacturing tools, 2015):

- Overproduction;
- Waste of inventory;
- Waste of transportation;
- Waste of waiting;
- Production of defects;
- Waste of over-processing;
- Waste of unnecessary motion.

All these seven categories of waste are responsible for energy and/or material losses. Thus, the implementation of the lean principles may take the form of implementing other BEMPs, e.g. 2.3 and 4.5. Overproduction leads to the consumption of raw materials and use of energy to make products which are not needed. Inventory waste implies goods which need to be heated, cooled, conveyed and lighted using significant amounts of energy. Packaging or other material for storage of work-in-progress (WIP) may also be inventory waste. Waste of transportation is also environmentally relevant as transportation of materials and products uses significant amounts of energy. Waste of waiting may not appear very relevant from an environmental perspective; however, the light, heat and running equipment all use energy while the staff is waiting. Defective components need to be reworked or disposed of, resulting in material and energy waste from the production as well as the reworking or disposal process. Over-processing refers to the material and energy put into a product that do not add value to the desired

[14] Life cycle thinking is already an important element of the mostly used environmental performance systems such as ISO14001 and EMAS.

product or that are not required by the customer. Unnecessary motion waste mainly refers to energy that is wasted by the unnecessary movement of machines, people or equipment. Also, excessive and unnecessary human motion can cause unsafe work conditions, lower productivity or poor quality which has consequences on energy and material efficiency.

For the fabricated metal products manufacturing sector, two additional areas for waste reduction are relevant: system integration/optimisation and technological improvements. Examples for system integration and optimisation are the reuse of waste heat between different processes, cascading waste water, etc. (see Figure 2.1).

Figure 2.1. Lean waste concept can be translated into energy terms and is strengthened by two additional levers (http://www.mckinsey.com)

	Types of waste	Definition	Example
A	I Overproduction	• Producing excess energy (input energy that is unused)	• Heating of empty ovens
A	II Waiting	• Consuming energy while production is stopped	• Unused conveyor belts keep running
A	III Transportation	• Inefficient transportation of energy	• Redundant compressed air networks
A	IV Over-specification	• Process energy consumption deliberately higher than necessary	• Furnace operated at higher then required temperature
A	V Inventory	• Stored goods use/lose energy	• Crude steel cools in storage, is then reheated for rolling
A	VI Rework/scrap	• Insufficient reintegration in upstream process when quality is inadequate	• Inefficient mixing of insufficient production charges in upstream processes
A	VII Motion (inefficient processes)	• Energy-inefficient processes	• Fixed motor running below optimal efficiency
A	VIII Employee potential	• Failure to use employees potential to identify and prevent energy waste	• Employees not involved in developing energy saving initiatives
B	System	• Failure to optimize system as a whole	• Waste heat from process A that could be used in process B
C	Technology	• Lack of TCO based investment decisions	• Avoid purchasing frequency convertors despite amortization time of 5 months

The implementation of the lean principles in a company can follow a five-step process (Cardiff University, 2015):

1. Identify customers and specify value: The starting point is to recognise that only a small fraction of the total time and effort in any company actually adds value for the end customer. By clearly defining value for a specific product or service from the end customer’s perspective, all the non-value activities - or waste - can be targeted for removal.
2. Identify and map the value stream: The value stream is the entire set of activities across all parts of the company involved in jointly delivering the product or service. This represents the end-to-end process that delivers the value to the customer. Once it is understood what the customer wants the next step for a company is to identify how it can deliver (or not) this to them.
3. Create flow by eliminating waste: Typically, when a value stream is first mapped, it is found that only 5% of activities add value (which can rise to 45% in a service environment). Eliminating this waste ensures that the product or service “flows” to the customer without any interruption, detour or waiting.

4. Respond to customer pull: This is about understanding the customer demand for the service and then creating the process to respond to this in such a way that a company produces only what the customer wants when the customer wants.
5. Pursue perfection: Creating flow and pull starts with radically reorganising individual process steps, but the gains become truly significant as all the steps link together. As this happens more and more layers of waste become visible and the process continues towards the theoretical end point of perfection, where every asset and every action adds value for the end customer.

Stock reduction

Stock reduction overlaps with lean management to certain extend. Companies in the fabricated metal products manufacturing sector often have an extensive stock of materials and goods in order to cope with flexible customer demand. The stock contains raw materials, WIP, purchased parts and components, semi-finished products, finished products, spare parts, etc. All these materials and goods require space, not only in the storage area, but also on the shop floor.

To apply stock reduction, there are available various approaches. Quick Response Manufacturing (QRM) is an example of a production approach, which drastically reduces the lead time and results in a lower stock. QRM applies cellular production layouts that typically require less floor space for equal levels of production compared to functional layouts (Figure 2.2). The reduction in required floor space and storage has impacts on energy and resource demand (e.g. for heating, lighting, infrastructure equipment) as well as waste generation and land use of the facilities.

QRM requires four fundamental structural changes that transform a company organised around cost-based management strategies to a time-based focus:

Functional to 'Cellular': Functional departments can be converted into QRM cells, in order to become the main organisational and operational units. QRM cells are more flexible and holistic in their implementation compared to other concepts, and can be applied outside the shop floor;

- *Top-down Control to Team Ownership*: Top-down control of processes by managers and supervisors in departments needs to be transformed to a decision-making structure in which QRM cells manage themselves and have ownership of the entire process within the cell;
- *Specialised Workers to a Cross-trained Workforce*: Workers (staff) need to be trained to perform multiple tasks.
- *Efficiency/Utilisation Goals to Lead Time Reduction:* To support this new structure, companies need to replace cost-based goals of efficiency and utilisation with the overarching goal of lead time reduction.

QRM requires engagement of the company executive management in order to ensure an integrated approach over different company departments like sales, materials management (supply chain), production organization, product design, etc. (Centre for QRM, 2015 and QRM Centre Europe, 2015).

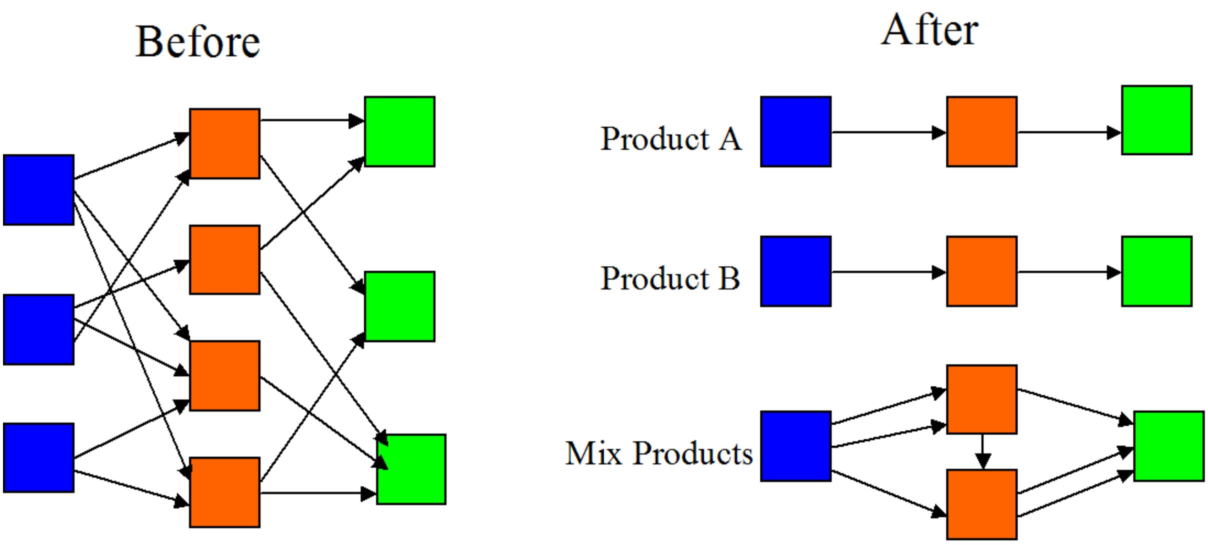


Figure 2.2. Organisation of the shop floor: before: traditional functional layout; after: cellular layout (Teim, 2010)

Achieved environmental benefits

Actively implementing an environmental policy and management targets leads to higher resource efficiency (materials), lower energy used and lower waste generation. More specifically, the implementation of a circular economy approach lowers the pressure on (scarce) resources (BSI, 2017b) and offers companies a possibility to decouple their economic growth from resource use and environmental impacts (BSI, 2017a).

Reuse and/or recycling of parts or products as well as repair services, maintenance and remanufacturing lead to a lower demand for virgin material, reduced metal waste generation across the product lifecycle and lower waste disposal rates at a product's end of life.

Effectively implementing lean principles as well as stock reduction measures in a company of the fabricated metal products manufacturing sector can lead to various environmental benefits related to the specific production process. The reduced demand for material is derived from input optimisation and/or waste reduction. Energy savings are generated at various production steps and reduce the direct and indirect CO_2 emissions of the company. Applications of lean management principles show that typically, when a value stream is firstly mapped, only 5% of activities are found to add value for the customer. This can rise to 45% in a service environment. Applying several management principles at Toyota manufacturing facility has e.g. led to a reduced energy usage per vehicle manufactured by more than 70% in 20 years (Idle, 2014). For the entire German fabricated metal products manufacturing sector, potential material reductions of 2 to 6% per year have been reported, with the highest potentials in the area of forging, pressing, stamping and roll forming of metal. Energy reduction potentials are estimated to range between 5 and 14% and are highest in treatment and coating of metals (VDI ZRE, 2013).

Less floor space for equal levels of production due to QRM can reduce energy use for heating, cooling and lighting per product manufactured, if additional production can take place within the same building (European business, 2015). It can also lead to a reduction of consumption of resources and generation of waste. In particular, reducing the spatial footprint of production, the need to construct additional production facilities, as well as the associated environmental impacts resulting from construction material use, land use, and construction waste can be reduced.

Appropriate environmental performance indicators

The following indicators[15] can help track progress with the implementation of the approaches outlined in this BEMP:

- Resource efficiency (kg finished products / kg of material input (alternatively: kg waste produced / kg input materials in case the kg finished products are not known)
- On-site energy use (kWh / kg kg finished product or manufactured part).
- Scope 1, 2 and 3 CO_2-emissions (kg CO_2 equivalent / kg finished product or manufactured part).
- Water use (l water / kg finished product or manufactured part)
- Mapping of material flows and their environmental relevance (Y/N)

Cross-media effects

No cross-media effects directly occur from implementing the approaches described in this BEMP into the environmental policy and management system of a company.

For QRM, rightsizing and dispersing environmentally-sensitive production processes throughout a plant can disrupt conventional pollution control systems. For example, a shift to cellular production is often accompanied by a shift to disperse, point-of-use chemical and waste management, which requires an adjustment in chemical and waste management practices. Similarly, shifts to multiple, right-sized painting and coating, parts washing, or chemical milling operations can alter air emissions control approaches and needs. If environmental requirements are not addressed adequately during the conversion to cellular layouts and rightsized equipment, the organisation can impact the environment adversely.

Operational data

Specific examples for some of the described measures in the fabricated metal products manufacturing sector are described below.

Example: Metaplast Gear Technology Kkt., Hungary

The company Metaplast Gear Technology Kkt., a gear manufacturer based in Hungary, implemented circular economy practices in different areas of their business. For instance, instead of disposing of packaging materials, these are stored and, if applicable, used for shipping at a later stage. Used office paper is also reused as packaging material. Another example is that Metaplast produces master gears with smaller diameters, resulting in energy and especially raw material reductions. Continuous improvement is facilitated through an employee reporting system, i.e. workers are encouraged to present their suggestions for measures for improvement and are rewarded for this with monetary benefits (Metaplast, 2016 and 2017).

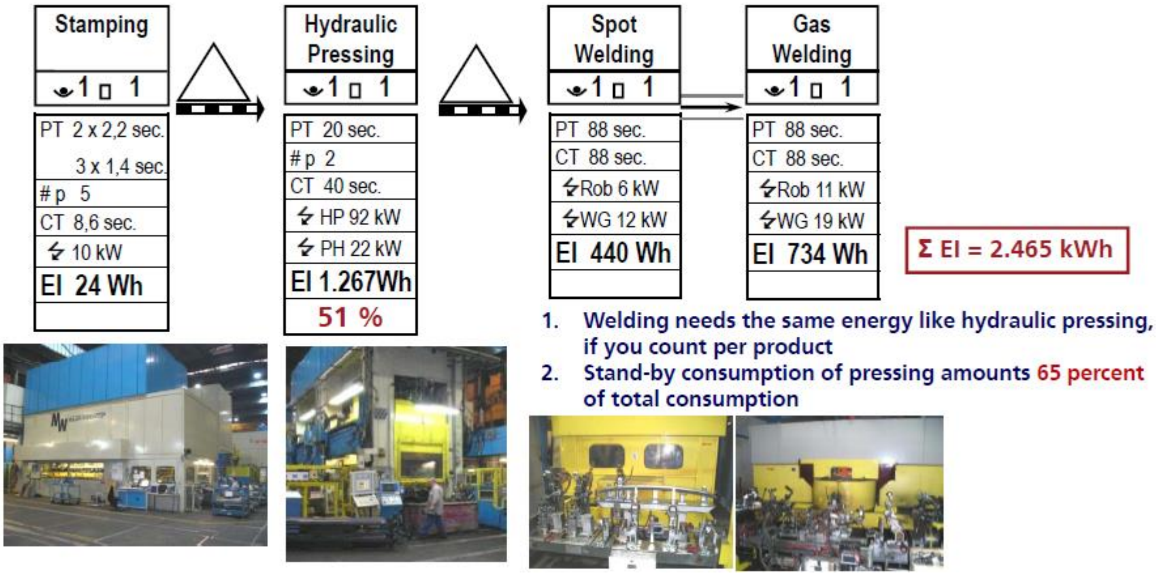
Example: lean management – value stream method by Fraunhofer IPA (Germany)

The Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) applied the principles of the Value Stream Method (VSM), which is a tool often applied to analyse the energy use per process. It allows the companies to analyse energy efficiency and

[15] Remark for the functional unit in the denominator of the differnet indicators used to express the finished products: the output (expressed in the denominator of the indicators as kg finished product or manufactured part, can be expressed in differnet ways: number of parts, kg of products, etc. depending on the type of products and their homogeneity/heterogeneity. Companies can choose suitable metrics to express the output, based on their operations.

eventually reduce energy use. Figure 2.3 presents the results obtained when the method was applied to analyse front bumper production using stamping, hydraulic pressing, spot and gas welding. The analysis showed that welding needs the same energy as hydraulic pressing when analysed per product. It was also found that the stand-by consumption for pressing amounts to 65% of energy use.

Figure 2.3. Production of a front bumper made of 5 parts in 4 production steps – calculation of energy intensity demonstrates effect of product related approach; EI = energy intensity (Fraunhofer, 2011)



Example: stock reduction– lead time and inventory reduction at Panimpex (Belgium)

The main activities of the SME Panimpex, based in Belgium, are punching, bending, soldering, and assembling of metal parts. Panimpex reconsidered its production processes in order to reduce the lead times and inventory. Table 2.4 gives an overview of the situation before and after the implementation of the stock reduction and QRM measures (Sirris, 2014):

Table 2.4. Panimpex results of QRM implementation (Sirris, 2014)

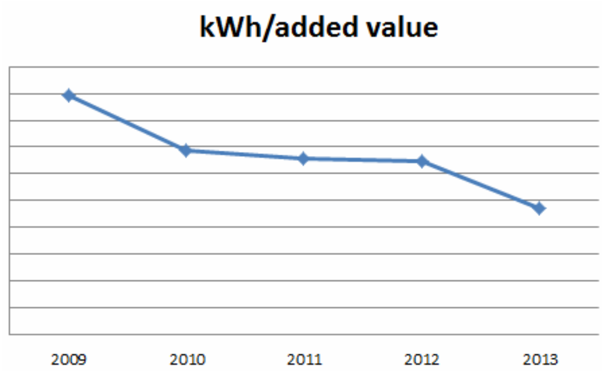
Before	*After*
Batch size: 50	Batch size: max. 10
Lay out: scattered work stations	Lay out: U- shaped cellular shape
Throughput: 4 days per product	Throughput: 2 – 4 hours per product
Inventory: large inventory and large work in progress quantities	Small inventory parts (almost no work in progress)

Example: stock reduction – lead time and inventory reduction at Provan (Belgium)

Provan is a metal working company and its main activities are sheet metal and steel pipe laser cutting, bending, forming, welding and assembling for a set of original equipment manufacturers (OEM) clients. Without quick response manufacturing (QRM) in place, Provan would need 260 additional stock locations due to a customer request for two new production sets. This would require the use of an additional warehouse building. Thanks to QRM approach below results are achieved:

- Lead time reduction from 4 weeks to 3 days;
- Improved quality;
- Reduction of 600 m² storage space;
- Almost 50% lower energy cost per added value (see Figure 2.4).

Figure 2.4. Evolution of the energy use (kWh) per added value after implementing QRM at Provan (Sirris, 2015)



Example: lean management – implementation at Atlas Copco Karlskrona (Sweden)

Atlas Copco implemented the lean management principles in a new-built manufacturing facility, in Sweden. Initially, they created a unidirectional flow where the number of operations is minimised by creating an optimal and efficient product flows. The second step was to balance all operations from incoming goods to delivery of finished products with the same pace to avoid overproduction and waste of resources. Furthermore, production is taken place upon order. The lead times are two weeks for up to 4 t machines and 4 weeks for up to 21 t of machines. With this method, components and pre-assemblies arrive to the manufacturing facilities on time without any significant delay. Finally, a complete quality check ensures the highest quality of the manufactured part/component/product (zero defects approach as it is called by the company). Summarising, the unidirectional flow and quality checks concepts are based on to make-to-order approach where every machining built is linked directly to a customer order. Therefore, the stock within the manufacturing facility is remained limited but sufficient (Atlas Copco, 2018). Thanks to the integration of these lean management principles, Atlas Copco at Karlskrona, managed to achieve the following:

- Storage space saved 43%
- Efficiency in production (gained) up to 15%
- Stock reduction 55%
- Smaller travel distance for roller in production 75%

Applicability

The approaches presented in this BEMP are broadly applicable by all types of companies in the fabricated metal products manufacturing sector, from SME to large companies. However, the application of circular economy and life cycle thinking can become increasingly complex for companies with a larger variety of products and processes.

The cellular approach (of the QRM tool) can be broadly implemented in most fabricated metal product manufacturing companies but it seems more suitable for single batches (small lot size).

Lack of sufficient in-house technical knowledge and the need for staff training at all levels and related budgets as well may be a limiting factor of the applicability of this BEMP.

Economics

Implementing measures for improved environmental performance has also positive economic impacts for a company, despite initial investments in training, new management systems or advanced technology. A circular business model reduces the dependency on raw materials and other resources that may be subject to shortages and thus rising prices. Furthermore, waste and energy reduction as well as optimised use of input materials reduce the associated costs.

The increasing awareness among business partners as well as end consumers for environmentally friendly products will also open new markets, provide new sales opportunities and competitive advantage for companies implementing comprehensive environmental policies. When applying life cycle thinking and a circular economy approach, companies may find a shift towards innovative products and services to be preferable in terms of environmental and economic performance.

Shorter lead times due to lean management and stock reduction improve quality, reduce cost and eliminate non-value-added activities within the company, while simultaneously increasing the company’s competitiveness and market share by serving customers better and faster. Solely looking at energy reduction, the total cost saving potential in Germany’s treatment and coating of metals branch is estimated to be about 146 million euros (VDI ZRE, 2013).

Overall, it is difficult to present economic figures for this BEMP since costs vary to large extend e.g. depend on the product portfolio, the type and intensity of the manufacturing operations etc. The investment costs can be rather clear, since they consist of specific components that depend on the above mentioned factors. However, the economic benefits and return of investment (ROI) are hard to be defined since they are heavily dependent on the current market conditions as well.

Driving force for implementation

The main driving force for implementation of this BEMP is the energy and materials savings. Their optimised use results not only in environmental but also economic benefits. Additionally, the implementation of its measures can make companies (more) flexible and reactive to customers demand and able to respond to unexpected changes.

Reference organisations

Atlas Copco is a Swedish manufacturer of industrial tools and equipment.

ConXtech Inc. is a Californian construction technology company. ConX is a mass-customizable, modular, prefabricated structural steel building system for high density residential, commercial, healthcare and institutional structures, as well as industrial pipe rack. The ConX System is a Cradle to Cradle Certified steel building system (ConXtech, 2015).

Metaplast Gear Technology Kkt. in Hungary applies a holistic waste reduction approach for office paper and packaging materials and continuously implements a variety of measures such as employee involvement in identifying environmental improvement actions (Metaplast, 2016, 2017).

Provan (BE), a company speciliased in tailor made metal solutions, implemented Quick Response Manufacturing (Sirris, 2015; European business, 2015).

Toyota Motor Manufacturing introduced the principles of lean manufacturing (Toyota, 2013).

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2.2 Collaboration and communication along and across the value chain

<table>
<tr><td colspan="6">SUMMARY OVERVIEW
BEMP is to collaborate with other companies within the sector, companies in other sectors and throughout the value chain. This collaboration can be organised as:
• Sustainable sourcing and procuring materials, energy and other auxiliary inputs required for manufacturing operations;
• Optimising resource by sharing energy and/or resources in an industrial symbiosis network;
• Engaging systematically with stakeholders on the development of new products and on the improvement of the existing ones.</td></tr>
<tr><td colspan="6">Relevant stages</td></tr>
<tr><td colspan="2">Cross-cutting issues</td><td colspan="2">Optimisation of utilities</td><td colspan="2">Manufacturing</td></tr>
<tr><td colspan="6">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td></tr>
<tr><td colspan="6">Environmental performance indicators</td></tr>
<tr><td colspan="6">- Percentage of goods and services (% of the total value) which are environmentally certified or with a demonstrably reduced environmental impact.
- Use of by-products, residual energy or other resources from other companies (kg materials from other companies / kg total input; MJ energy recovered from other companies / MJ total energy use).
- Systematic stakeholder involvement with a focus on improved environmental performance (e.g. in product design, improved supply chain environmental performance, sustainable sourcing, cooperation for improved waste management) (Y/N)
- Purchase of second-hand machines or use of machinery from other companies (Y/N)
- Amount of packaging waste (kg of packaging waste / kg finished product or manufactured part)</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="4">This BEMP is broadly applicable to all size of companies in the sector, including SMEs.
Lack of sufficient in-house technical knowledge and the need for staff training implies extra costs that may constitute a significant barrier for some companies, especially for SMEs.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="4">All purchased goods and services meet environmental criteria established by the company.
Collaboration with other organisations to use energy and resources more efficiently at systemic level.
Structural engagement of stakeholders in the development of more environmentally friendly products.</td></tr>
<tr><td colspan="2">Related BEMPs</td><td colspan="4">2.1, 2.6, 2.7</td></tr>
</table>

Description

In order to optimise processes, innovate and use energy and resources more efficiently at a systemic level, it is key to collaborate with other companies within the sector, companies in other sectors and throughout the value chain.

Three major areas of collaboration can constitute best practice:

a) sustainably sourcing and procuring materials, energy and other manufacturing inputs;

b) optimising resource use e.g. by sharing energy and/or resources in an industrial symbiosis network.

c) engaging systematically with stakeholders on the development of new products through co-design and open innovation and improvement of the environmental performance of manufacturing sites and existing products.

a) Sustainable procurement

Companies can improve their environmental footprint by applying environmental criteria when sourcing goods and services from their suppliers.

"Green" procurement is an approach that can take various forms, depending on the leverage of the company as a client and the availability of greener options on the market concerned. The following steps can be followed by organisations wishing to green their purchases:

- select more environmentally friendly goods and services, for instance by comparing and selecting products bearing environmental information, ideally 'type III' (third-party verified). Examples of such schemes include Environmental Product Declaration (EPD) for materials.

- select suppliers who are engaged in a process of environmental management and continuous environmental performance improvement, e.g. undertaking actions like reduction of packaging used or use of reusable packaging, applying lightweight packaging methods. This is usually possible by choosing suppliers who have adopted an advanced environmental management system (e.g. EMAS).

- identify improvement opportunities by collaborating with existing suppliers and seeking new ways to source products or services with enhanced environmental performance.

Beyond environmental performance, some companies can also be interested in broader dimensions of sustainable development such as social aspects, and adopt parallel approaches such as Responsible Sourcing. This may also be facilitated through recognised standards[16].

Integrating sustainable sourcing within the organisation's environmental management and increasing the environmental requirements from suppliers helps spread better practices throughout the value chain. Companies reporting on their environmental performance and requiring input from their suppliers can use for instance the Global Reporting Initiative’s (GRI) standards on Procurement Practices or Supplier Environmental Assessment (GRI, 2016).

b) Industrial symbiosis

An industrial symbiosis is a local collaboration scheme where different companies buy and sell each residual type of products from other companies, resulting in mutual economic and environmental benefits. This means that two or more companies become interdependent on each other for their resource or energy streams. For instance, waste heat generated in one company can be used as a sustainable source of heat which is required in a second company. Along the same lines, a company may buy pre-owned equipment (e.g. metal working machines) from another company, with the prerequisite that the equipment meets all requirements and technical specifications of the interested manufacturing company. Figure 2.5 shows the functioning of industrial ecology, the overarching frame for industrial symbiosis. A holistic management system called the Total Efficiency Framework, including amongst others industrial symbiosis principles, is currently being developed at a European level (MAESTRI, 2017).

[16] Such as the Aluminium Stewardship Initiative’s (ASI) requirements for sustainable sourcing of aluminium under their Chain of Custody (CoC) Standard (ASI, 2017) or the BES 6001 Responsible sourcing of construction products, which can be applied to any material, including metal products, used in the construction industry (BRE, 2015)

Examples from the fabricated metal products manufacturing sector are linked to:

- reuse of waste streams, including material waste from metal product fabrication, e.g. cake, scrap, coating powder and solvents, as well as energy, e.g. steam, hot water or air;
- closing the loop of valuable materials, e.g. special metal alloys;
- linking materials demand or equipment need with waste streams or standby periods, back-up or redundant equipment in other companies.
- identifying logistical optimisation opportunities, e.g. empty return routes for a neighbouring company which can be put to profitable use.

Figure 2.5. Representation of Industrial Ecology processes (GPEM, 2015)

To get started with industrial symbiosis, the following steps can be followed:

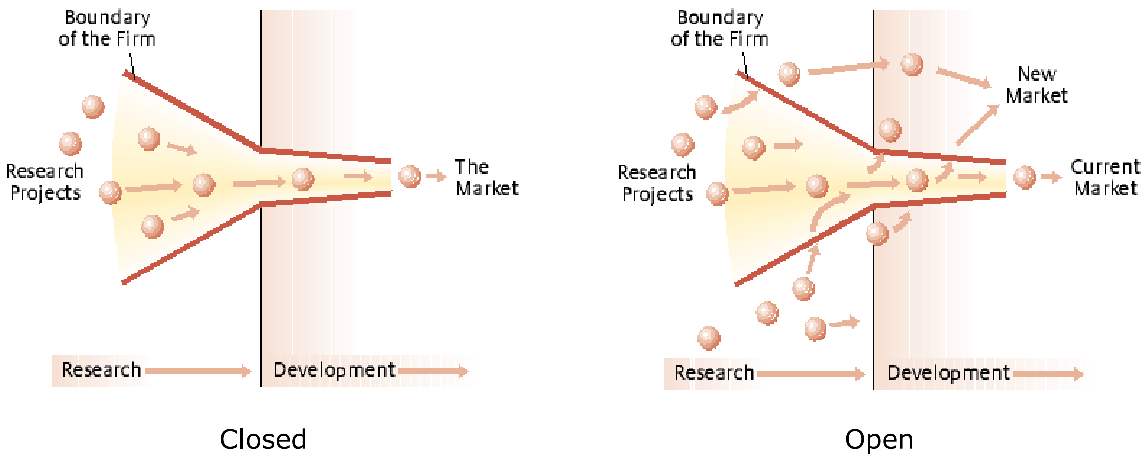
- Identify opportunities by mapping energy or resource streams and their value/costs;
- Map all stakeholders in the process;
- Search (locally) for partner companies;
- Identify the knowledge gaps and support needs to further elaborate the opportunity;
- Define and set up (small-scale) experiments;
- Gradually extend the number of involved partners to build up a more robust network.

c) engage systematically with stakeholders

<u>Engaging with stakeholders for the design of new products</u>

Tools that can be used for this task are the co-design and open innovation. Using direct input and feedback from customers and end-users in the design and engineering phase provides opportunities for environmental friendly solutions and designs. Making use of a growing group of experts from various sectors offers the chance to capture new insights and new break through ideas. In contrast with closed innovation, where research and development is performed in-house and no or little external knowledge is used, open innovation makes use of external partners to achieve research and development. With open innovation the boundaries with the surrounding environment of the company are easily crossed and own ideas are brought to the market (Figure 2.6).

Figure 2.6. Innovation funnel, closed vs. open innovation (Chesbrough, 2003)



Collaboration between companies in the sector and downstream (end-)users provides in depth insight in design requirements. The open innovation creates a platform for an iterative design approach allowing fast validation of design ideas and concepts. Open innovation also makes optimal use of available knowledge and expertise inside and outside the company.

Co-design, co-engineering and open innovation exist in a large variety of forms, i.e. from a single brainstorm session with a (limited) number of stakeholders to a full process from designing, engineering and validating up to marketing of newly developed products. In order to implement co-design and open innovation with (end-)users, controlling the risks and setting up processes and methods for collaboration with clear rules for all partners is key. Risks associated with co-design comprise e.g. the costs and resources for organisation (people, time and money), the complexity of such projects and the management of expectations and objectives (Steen, Manschot and De Koning, 2011). Clear rules need to be defined, understood and acknowledged by all partners involved in the open innovation. Benefits for all partners have to be mutually recognized as well. Often third party process guidance is used in order to control the risks.

Strategies for open innovation in SMEs are (Vanhaverbeke et al. 2012):

- Vision: Frequently, a (radically) new vision of entrepreneurs or managers is the starting point for the business model of SMEs;
- The network of partners: the SMEs establish a network of external partners. Partners may be technology partners such as universities, research labs, or other companies. The size of the network is determined by the type of products or services the SME wants to launch. A network of partners is only viable when each partner is better off compared to not participating in the network;
- Building strong ties to cope with environmental and relational risks: to tackle risks of open innovation networks, strong personal ties between key managers and actors of the network are required;
- Dependence on partners' intellectual property (IP). Low-tech SMEs can rely on others' IP, or they co-develop technological innovations. Most often small firms have negotiated technology agreements such as licensing deals with their partners;
- A stepwise approach: The start for changing the business model for SMEs is often a (radically) new product or service. This is followed by a continuous process of open innovation, that may follow a stepwise approach;
- The benefits and cost of relational capital: Relational capital plays a central role in developing an open innovation based business model. The competitive strength of

the SMEs is no longer (only) related to its internal competencies, but (also) to its network of relationships. After some years, an SME has a large network of companies upon which it can rely.

Co-design and open innovation in the fabricated metal products manufacturing sector also provides the possibility for SMEs to set up collaborations with large, globally operating companies that can have access to knowledge, technologies, markets that would otherwise be out of reach.

A broad and holistic approach for the development of innovative products and businesses is eco-innovation, which aims at reducing environmental impacts and using resources more efficiently in both products and production processes (European Commission, 2015). Similar to co-design and innovation, value chain engagement and external partnerships are essential for successful eco-innovation and support companies in identifying their adverse environmental impacts along the value chain and working towards reducing them (UNEP, 2017).

Engaging with stakeholders for the improvement of the environmental performance of existing products

Carrying out meetings with stakeholders allows improvements of the environmental performance for the existing products (and also may bring insights for the improvement of the environmental performance of the manufacturing site). Elements described in the above point (for the design of new products) are relevant for this point as well. In fact, certain elements designed for new products can be also applied for existing products, making them greener (for instance by replacing one single component with another more environmental friendly). One representative example is the use of packaging where manufacturers can inform suppliers of available solutions and alternative options (e.g. use of reusable packaging and/or returnable packaging, lightweight packaging), which improve the environmental performance of the existing products. Therefore, manufacturers within the same or different sector can set their specifications and requirements to suppliers by drafting proposals for improving the environmental performance of different areas e.g. packaging[17].

Achieved environmental benefits

Cross-sectoral and value chain collaboration between companies can lead to an optimised use of resources (e.g. materials, equipment, capacity) and energy as well as to a more rational management of waste. Thanks to these optimisations, significant reduction of CO_2 emissions and pollutant emissions can be achieved throughout the entire value chain.

In the case of industrial symbiosis, sharing material streams or energy between companies also reduces the impact on land use and biodiversity as less space is required for the individual companies to generate the required resource.

Co-design and open innovation in the fabricated metal products manufacturing sector can help design products with a reduced overall environmental impact. Achieved environmental benefits can be e.g. a reduced weight of the manufactured product, reduction of waste produced during manufacturing and/or disassembling, reduction of resource use and emissions.

The reduction of packaging or the use of reusable or returnable packaging has clear environmental benefits. In fact, results from other sectors and applications have shown a

[17] Manufacturers can take inspiration from/consult WRAP (2010) guidelines when consider moving into the use of reusable packaging.

reduction of up to 88% of the GHG emissions and significant reductions in the raw materials used.

Appropriate environmental performance indicators

The appropriate environmental performance indicators for this BEMP are listed below:

- Percentage of goods and services (% of the total value) which are environmentally certified or with a demonstrably reduced environmental impact.

- Use of by-products, residual energy or other resources from other companies (kg materials from other companies / kg total input; MJ energy recovered from other companies / MJ total energy use)

- Purchase of second-hand machines or use of machinery from other companies (Y/N)

- Systematic stakeholder involvement with a focus on improved environmental performance (e.g. in product design, improved supply chain environmental performance, sustainable sourcing, cooperation for improved waste management (Y/N)

- Amount of packaging waste (kg packaging waste / kg finished product or manufactured part)

Cross-media effects

Generally, there are no cross media effects from the implementation of the measures of this BEMP.

However, when companies implement the industrial symbiosis, they need to assure that the overall environmental impact is reduced. In particular, there is no shift of the impact from one life cycle phase to another when implementing industrial symbiosis or other forms of sharing of resources (the residuals/by-products from the processes of the companies) between companies. For instance, the additional environmental impacts due to transport and reprocessing operations for the use of a by-product as secondary raw material need to be compared and assessed with the impact of the production, transport and use of the virgin material.

The same applies to open innovation and co-design, which would not necessarily focus on a reduction of the environmental footprint. Therefore, the focus and scope of the innovation process need to be controlled throughout the entire process in order to target environmental benefits and avoid negative cross-media effects.

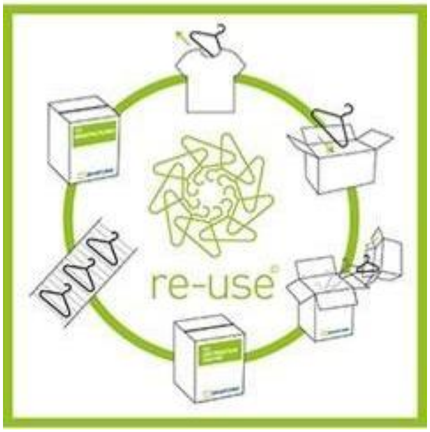
Operational data

Case study: Brainform (UK) – garment hanger re-use

Brainform (UK), a garment hangers manufacturer, has realised benefits by applying a circular business model by closing the materials loops of their products. The company belongs to both the fabricated metal products manufacturing and plastics processing sector (steel parts formed from wire & plate which are integrated in plastics parts). Their closed loop process allows the company and its clients - major retailers and garment suppliers - to work together. By re-using their hangers, retailers can reduce costs and improve efficiencies by extending the lifespan of a garment hanger beyond a single use.

The loop works as follows: after being contracted by a new partner, Brainform develops a new garment hanger solution, which starts with supplying virgin product into the market. Manufacturers buy these hangers and deploy them before shipping their products. The garments are distributed and during purchase, the retailer collects the hangers, sending them back to distribution centres. In a next step, the hangers go back to one of three main re-use centres where they are sorted, repackaged and distributed back to garment-producing regions. Hangers that cannot be re-used are shredded and used to make new products (Figure 2.7).

Figure 2.7. The Brainform re-use program (Brainform, 2015)



Brainform cooperates with companies that have in place injection moulding production to manufacture the virgin hangers, rather than owning the factories and equipment themselves.

By moving to re-use meant that Brainform became largely independent from fluctuating oil prices (significant for the plastics parts), enabling them to remain competitive and improving client relationships. The company collects and shreds hangers for a number of clients, including those who are not part of the re-use program.

By moving from the initial linear approach to a closed loop of the materials, Brainform is demonstrating multiple benefits, such as materials cost savings, greater resilience from price volatility, closer client relationships and new jobs (Brainform, 2015).

Case study: VOM (BE) - reuse of powder coating

The Belgium association for surface finishing techniques, Spooren, (2012) set up a management scheme providing different possibilities for reuse and recycling of waste from the powder coating process. For reuse as powder coating, the waste streams have to be collected separately by colour and may not contain impurities (like dust). The reuse companies are chemical firms who produce powder coatings (e.g. Fina Research S.A. and E.I. Du Pont de Nemours & Co).

An alternative option is to use the waste from the powder coating process to produce other, new materials (composites). This option is useful for powder coatings containing materials like urethane, epoxy, acryl or polyester. There is no necessity to keep colours separately whereas small impurities (like grind, stones) are acceptable. Steelcase and GMI Composites (the 2 are companies participating in this scheme) have set up a collaboration to recycle waste from the powder coating process.

Case study: Steelcase (US) – reuse of waste from powder coatings

Steelcase, an office furniture manufacturer, provides ergonomic seating products through leasing. The steel parts of the seats are powder coated in their manufacturing plant. By creating new relationships the overspray and excess coating powder of

Steelcase is now used as a resource for GMI Composites. GMI Composites uses the powder as a matrix material to manufacture light weight manhole systems using a sheet moulding compound process[18].

The two following examples from the UK, deal with the National Industrial Symbiosis Programme (NISP). NISP is an organisation based in the UK that identifies mutually profitable transactions between companies. The aim is to advise the participant companies in the NISP on how to bring into use the underused or undervalued resources (such as energy, waste, water and logistics). In this initiative, all type of companies can participate belonging to different sectors.

Case study: DENSO Manufacturing (UK)

The main objective was to support DENSO manufacturing (UK) in finding more sustainable waste treatment. The company manufactures air-conditioning units for the automotive industry. The company had already established a sustainable disposal route for waste filter cake generated as part of its process, but identified an option that required less transportation with greater environmental benefits. The company attended a number of NISP 'Resource Matching' workshops in order to get inspiration and advice on how could solve their issue. The NISP practitioners looked at all manufacturing processes in order to identify ways in which to further eradicate waste at source and effective recovery, reprocessing and reuse options when waste was unavoidable. The filter cake produced in the effluent treatment plant at DENSO has 70% moisture content. NISP recommended implementing an on-site solution using waste heat from the company's manufacturing systems to dry the cake (Figure 2.8), making it suitable for use in alternative processes. The new system has reduced transportation and the material is now used in three additional processes, significantly impacting on the company's carbon footprint. Once dried, the product is sent to another company, where it is crushed for use as an active agent in the absorption of oil and solvent. This agent is then employed as a fuel source, before the residual:

- Reduction of 18 tonnes a year of waste filter cake by drying it and reducing moisture content of the cake;

- Road transport requirements were reduced by 200 miles per year (CO_2 reduction).

Figure 2.8. DENSO filtercake (NISP, 2012)

[18] This process was also patented (US 20080153932 A1, 2007).

Case study: Band Saw manufacturer (UK) & CTS Environmental Services Ltd – recycling metals form waste

Manufacturing band saws require grinding operations which generates waste. This waste consists of grindings and mineral oil (coolant) in the form of a cake (Figure 2.9). Initially, this grinding cake was treated as hazardous waste. The concentration of the hazardous component was below the hazardous waste threshold level. A recycling facility was found to recycle the metals in the cake, resulting in:

- A reduction of 80 tonnes/year of hazardous waste;
- A CO_2-reduction of 153 tonnes/year;
- 80 tonnes/year of materials recycled.

Figure 2.9. Oily grinding cake (NISP, 2009)

Case study: AGFA (BE, DE) - Closed loop of aluminium offset printing plates

One of AGFA's activities is the manufacturing of offset printing plates. AGFA modifies the surface of AA 1000 alloy aluminium (+99.3% pure Al) to produce products with specific quality for optimal printing performance. The offset printing plates are perceived as consumables for the suppliers and are in general valorised by the printers as high quality (pure) aluminium. Due to the pressure and volatility of the prices, Agfa decided to try to close the material loop. Their objectives were: avoid 'downcycling' (Figure 2.10) of used plates by developing a recycling process for lithographic aluminium, no impact on product quality, reduce the carbon footprint, asses the environmental impact of the reverse logistics (for Agfa and for the customer) and no increase of the product cost. Phase 1 only involved Agfa's production plants, while phase 2 involved their European customers (Figure 2.11).

Figure 2.10. Agfa's old scrap flow (Pellegroms, 2015)

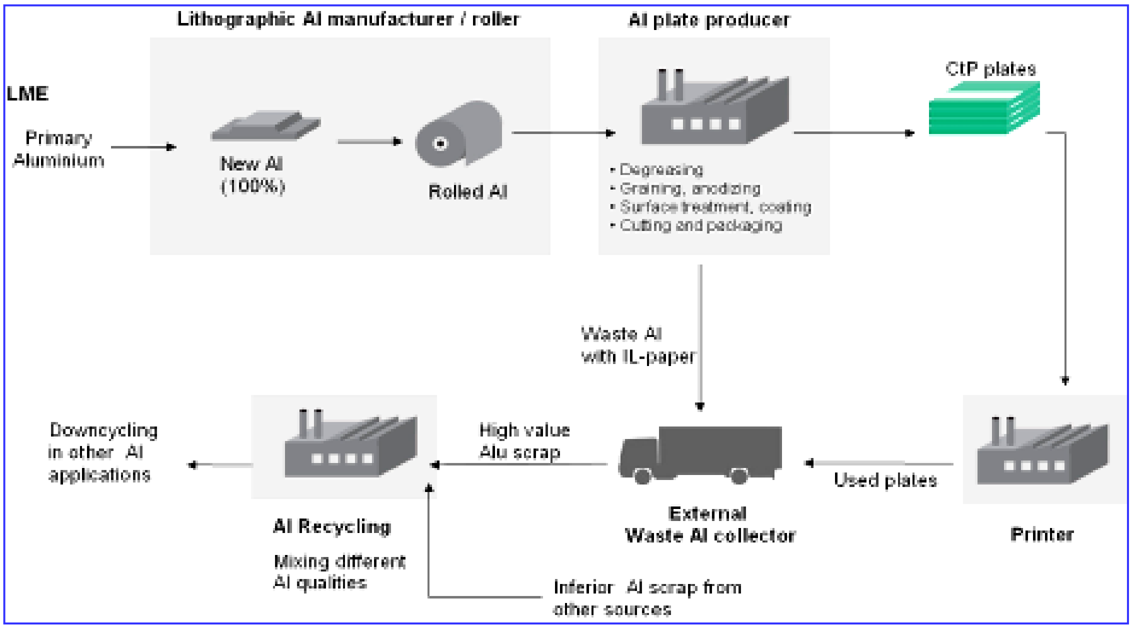
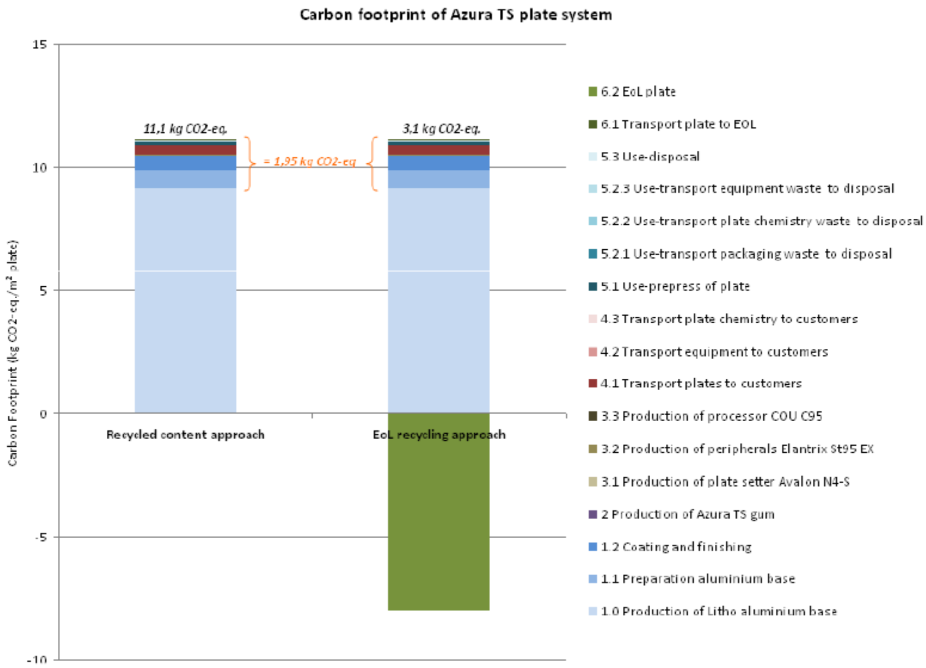


Figure 2.11. Agfa's new scrap flow (Pellegroms, 2015)

The product quality was controlled, while they gradually increased the recycled content from 10% up to 100%. Validation by own labs, as well as blind tests by selected customers assured the quality was maintained. In phase 2, a new business model in which printing plates are leased required new marketing and sales targets and increased the need for additional partners specialised in the reverse logistics and recycling.

Since aluminium production is responsible for 80% of the climate change impact, the achieved environmental benefits in this case is significant. The CO_2-footprint has decreased from 11.1 kg/m² to 3.1kg/m² (Pellegroms, 2015; Verschave, 2012; Figure 2.12).

Figure 2.12. Carbon footprint Agfa (Verschave, 2012)



Case study: Volvo Cars (BE) - Use of waste heat from neighbouring company

StoraEnzo, a producer of paper mill has a CHP (Cogeneration or combined heat and power) installation on biomass. StoraEnzo uses the electricity itself. The heated water is transported to the neighbouring company, Volvo Cars.

As a direct result, Volvo Car has reduced its use of fossil fuels for heating purposes. The CO_2 emissions have decreased by 15 000 tonnes per year, a net decrease of more than 40% of total CO_2 emissions of the plant (StoraEnzo, 2014).

Case study: Steel Service Centre (BE) – Collaboration with food producer

The SME Steel Service Centre (BE) is a weld shop that has invested in photovoltaic cells to provide electricity for their manufacturing processes. What is different from other PV installations is that they are not connected to the grid to supply the surplus energy. Surplus energy arises in the weekend, as no welding operations take place at that moment. The company provides its surplus energy to its neighbouring company Quality Meat Products, a company that has a large and almost invariable energy demand for cooling of their meat products.

Case study co-design and open innovation: ConXtech (US) - Novel joining technique to improve deconstruction of buildings

Deconstruction of building with bolted structural elements results in a loss of re-use potential due to inability to disassemble economically the joints between the metal components like I-beams. The current practice is that those joints are cut and the remaining steel scrap is recycled. Novel joining techniques could only be designed by in depth knowledge and collaboration with building and assembly actors.

ConX structures are typically lighter and assembled 2 to 4 times faster than conventional steel or concrete structures. Using the ConX System typically results in cutting total tonnage, eliminating waste in field work, and reducing risk with a stronger, safer structural system and reduce on site equipment usage (http://www.conxtech.com). Similar projects include Quicon, ATLSS, ConXtech and Girder Clamps.

Figure 2.13. The ConX® System (Cradle to Cradle Certified Products Registry, 2014)

Case study co-design and open innovation: Curana (BE) - Design and innovation management

Curana is a trendsetter and manufacturer of bike equipment and bike accessories. The design and innovation management at Curana follows a structured procedure (http://www.curana.com):

- Step 1: Exploration – Monitoring social changes, fashion trends, technology developments, customer needs, brands research, value chain analysis, participation in learning networks.
- Step 2: Design – Creative sessions to generate ideas, handmade models of the new concepts, incorporation of innovative technologies for a simpler and cheaper assembly, identification of the right technology and materials, synergies with production partners and knowledge centres.
- Step 3: Promotion – Interactive concept presentations to clients demonstrating solutions to problems, listening to clients' feedback, good efforts in brochures and packaging, image building and creation of a corporate identity (innovation power) and international design awards.
- Step 4: Realization – Development of high-end 3D model of the concept in collaboration with engineering partner, virtual verification with knowledge partners, rapid prototyping → managing networks of external innovation partners.

Case study: cross sectoral collaboration for the German automotive sector

In Germany several automotive companies (OEMs and suppliers) joined a "Waste Disposal Portal". The aim of this cooperation is to ensure a proper disposal of waste from the participants and with this to reduce the legal risks. As a measure, participants have agreed on a standard on how to audit their waste disposal partners. The audit reports are published on an internet page that is available for all partners. With sharing these reports, the effort for each participant is reduced and waste disposal companies are motivated to ensure a proper transport, storage and handling of the waste. In their contracts, the Portal participants and the waste disposal companies agree to special terms and conditions, in particular regarding the audits and the spreading of the audit reports (Schaeffler AG, 2016).

Applicability

This BEMP is broadly applicable to all types of companies of the sector, including SMEs. However, there are some factors that limit its applicability and these are summarised below:

- The intellectual property or confidentiality issues: companies develop patents or have other information on products or services that is not publicly available. This could limit the willingness to share information with the stakeholders.

- Lack of knowledge of stakeholders (e.g. on how to select the proper stakeholders/suppliers to collaborate with), and on how to manage effectively external stakeholder involvement processes;

- Resistance to changes or insufficient change management capacity. This can be both a problem in-house and with customers, since there are cases where customers that do not want to co-design an improved version of a component, even this action would lead to reduced costs (on top of the environmental benefits).

- Length of the supply chain, which can limit the opportunities to work across the value chain.

- Market conditions where the implementation of this BEMP in companies whose customers/clients may reward their efforts is simpler and may yield higher return of investment.

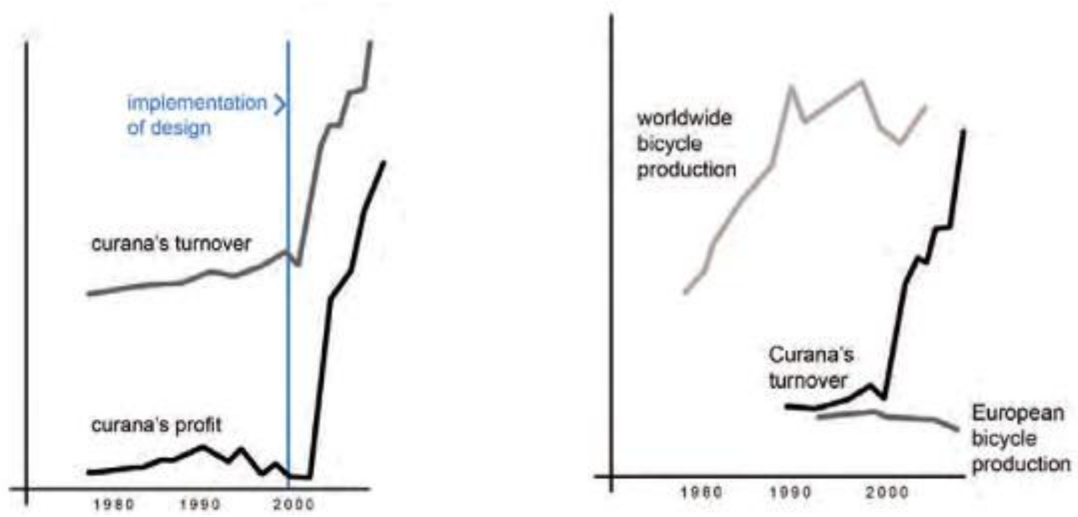
Economics

The economics of cross-sectoral and value chain collaboration, highly depend on the business case.

The case of DENSO Manufacturing (UK) supported by the matchmaking initiative NISP (see Operational data) resulted for example in a cost saving of £5,000 (€ 6,600) as a result of waste minimization (reduced quantity of cake to be disposed of) and transport (NISP, 2012). Similarly, AGFA (see case study in operational data section) was able to reduce significantly the volatility of price of their aluminium material by closing the material loop.

Efficiently controlling open innovation or co-design processes is a key factor to prevent overhead costs and efforts to offset the envisaged benefits. Once these risks are controlled and the process is implemented, co-design and innovation can speed up the design and engineering process while safeguarding the customer expectations and market acceptance. The process can capture new break-through ideas from (experts) all over the world and can lead to a faster time to market. The improved economic performance for the bike producing company Curana after implementing open innovation is shown in Figure 2.14.

Figure 2.14. Curana's turnover and profit in relation to the bicycle production (Bosch, 2010)



Driving force for implementation

The main driving force for this BEMP is the increased efficiency of resource and energy use leading to an overall cost reduction and better business reputation. The collaboration initiatives also result in significant knowledge acquisition and increased resilience by the extending partnering network.

Reference organisations

ActClean Matchmaking shows a database of cross sectoral good practices and strives to become the matchmaking platform for SME's: http://www.act-clean.eu/index.php/Act-Clean-Matchmaking;182/1

ConXtech Inc. is a privately-held construction technology company in Pleasanton, CA, modular, prefabricated structural steel building system for high density residential, commercial, healthcare and institutional structures, as well as industrial pipe rack. (http://www.conxtech.com/company/history/).

Corda Campus which supports the fruitful partnerships and a exchange of knowledge and ideas http://www.cordacampus.com/nl/corda-campus/campus/corda-concept/open-innovatie.

Curana is a worldwide manufacturer of bike equipment and bike accessories (http://www.curana.com/).

Dokota (BE) is a company working together with Fabricated Metal Products companies (and other) to reuse their waste from the powder coating lines. http://www.dakotaworldwide.com/

FLOOW2 is the business-to-business sharing marketplace where companies and institutions can share equipment, services, and the skills and knowledge of personnel.

Companies can provide or request specific equipment, or service. The transactions can be based on borrowing, renting purchasing agreements. It allows companies to lower the risk while experimenting, reduce costs or generate extra income and connect with other companies currently outside their horizon. The benefits are: Stimulation of servitisation and discouragement of ownership by sharing equipment and optimal resource use (less equipment needed to deliver the same performance). http://www.floow2.com/sharing-marketplace.html.

Harvestmap (Oogstkaart in Dutch) is an online marketplace for redundant and second hand materials. Harvestmap/Oogstkaart allows companies or individuals to make an inventory of their supply of materials, components or even buildings to Superuse (see below). All materials, ranging from small quantities to continuous flows of (industrial) leftovers are presented. Registration to Superuse.org gives access to Oogstkaart too. Participation allows you to share supply, provide tips to the community and find available resources in the neighbourhood or the surroundings of a project.

Holst Centre is a R&D centre that develops technologies for wireless autonomous sensor technologies and flexible electronics, in an open innovation setting and in dedicated research trajectories http://www.holstcentre.com/.

Jaga Open innovation for radiators: http://www.sciencebusiness.net/eif/documents/Open-innovation-in-SMEs.pdf.

Metal Valley (NL). Metal Valley Netherlands offers partnerships with entrepreneurs, specialists and students to create new opportunities for the entire metal sector through open innovation http://www.metalvalley.eu/en/innovation.

NISP, the National Industrial Symbiosis Programme, has been in place in the UK since 2003, and is the world's first National Industrial Symbiosis Programme. NISP provides a platform to inspire businesses to implement resource optimization and efficiency practices, keeping materials and other resources in productive use for longer through industrial symbiosis. (http://www.nispnetwork.com/). In Belgium there is a comparable programme, called SmartSymbiose (http://www.smartsymbiose.be).

Open Manufacturing Campus aims to be not only a physical place where innovative manufacturing companies can establish themselves, but also a virtual Open Manufacturing Community that reaches far beyond the boundaries of the physical campus (http://openmanufacturingcampus.com).

Steelcase (US) an office furniture manufacturer in the Fabricated Metal Products sector provides ergonomic seating through leasing. Their steel parts are powder coated in their manufacturing plant. By creating new relationships the overspray and excess coating powder of Steelcase is now used as a resource for GMI Composites http://www.steelcase.com/

Superuse.org is an online community of designers, architects and everybody else who is interested in inventive ways of reuse of materials, elements and components. The site allows you to post items at various scales within the reuse-topic. All examples of small commodities, furniture, interiors, buildings and reuse on urban scale are welcomed. Next to exhibiting applications, we promote the development of knowledge on the subject by starting up discussions, adding historical background and allowing user comments.

Volvo cars (BE) uses heat water of a neighbouring company and reduces its direct emission of greenhouse gasses http://www.volvocargent.be/

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2.3 Energy management

<table>
<tr><td colspan="6">SUMMARY OVERVIEW
BEMP is to optimise energy use by implementing an energy management plan including systematic and detailed energy monitoring across manufacturing sites at the process level, comprising the following elements:
• Establishing an energy policy strategy and detailed action plan;
• Gaining commitment from senior management;
• Defining ambitious and achievable targets and achieve continuous improvement;
• Performance measurement and assessment at the process level;
• Communication of energy issues across the organisation;
• Staff training and encouragement for active engagement;
• Investment in energy efficient equipment and consideration of energy efficiency in procurement processes.
The plan can be based on a standardised or customised format, such as ISO 50001 or as part of a global environmental management system like EMAS.</td></tr>
<tr><td colspan="6">Relevant stages</td></tr>
<tr><td colspan="2">Cross cutting</td><td colspan="2">Optimisation of utilities</td><td colspan="2">Manufacturing</td></tr>
<tr><td colspan="6">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td></tr>
<tr><td colspan="6">Environmental performance indicators</td></tr>
<tr><td colspan="6">- Energy use per manufactured product (kWh / kg finished product or manufactured part)
- Energy monitoring system at process level (Y/N)
- Budget allocated to all energy efficiency improvements with return on investment up to five years (€/yr)</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="4">The BEMP is applicable to all types of companies in this sector, including SMEs.
The lack of in-house technical knowledge, especially in smaller companies can be a limitation for the applicability of this BEMP. Additionally, improper integration of the elements of the energy management system and weak communication across the organisation can downgrade the performance and effectiveness of the energy management system in place.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="4">Continuous energy monitoring at process level is implemented and driving energy efficiency improvements</td></tr>
<tr><td colspan="2">Related BEMPs</td><td colspan="4">2.1, 2.7, 3.1, 3.2, 3.3, 3.4, 3.5, 4.3, 4.4, 4.6, 4.7, 4.8</td></tr>
</table>

Description

Optimised energy management can significantly improve the environmental performance of fabricated metal products manufacturing companies. Due to the wide use of energy across different production processes, measures or techniques for improved energy efficiency related to specific supporting or manufacturing processes are presented in the respective BEMPs[19]. This BEMP on energy management presents an overall approach to reduce and optimise energy use by applying an advanced energy management system at organisation and process level. Many companies of the fabricated metal products manufacturing sector have already in place an energy management system (EnMS), either on a standardised format e.g. ISO14001 or 50001, or even part of the environmental management system like EMAS. Best practice in setting up an advanced energy management plan, goes beyond the implementation of a standardised EnMS. Consequently, its aspects are further described in this BEMP.

Energy management is also covered in the best available techniques reference document (BREF) on energy efficiency (ENE)[20] which provides guidelines for optimising energy efficiency and lists broadly applicable Best Available Technologies (BAT). Some examples for BAT are to prepare and publish regular energy efficiency statements, to identify the aspects of an installation that influence energy efficiency by carrying out an audit, to establish energy efficiency indicators and compare them with other sectors and benchmarks, and to maintain expertise in energy efficiency and energy-using systems (European Commission, 2009).

The initial steps in developing an effective energy management strategy involve assessing the drivers of an organisation's energy use, monitoring it, and identifying areas for improvement. Actions will then be deployed to reduce energy use as well as reduce the impact of energy supply.

Energy efficiency needs to be considered across all operations of a company, including supporting processes like procurement and internal logistics. For instance, when purchasing new machines or (auxiliary) equipment, the energy demand of the envisaged goods should be taken into consideration. Likewise, internal logistics, e.g. the transport of materials and goods from delivery to storage to the place of use (and back to storage) can also have significant impacts on the overall energy use. It is thus important to systematically analyse each step of the direct and indirect processes inside and outside the company and identify e.g. redundant transports or improve the local setting. To go beyond common or good practice, external logistics or other indirect aspects can be considered as well (e.g. energy demand along the supply chain, transportation of materials and input products to the company site, commuting of workers/staff).

An EnMS also benefits from enhanced awareness of the employees for energy efficiency. Staff training may lead to proactive identification of savings potentials or innovative ideas for reducing the energy demand. Furthermore, awareness raising and training increase the acceptance and understanding for the implemented measures.

The purpose of an EnMS is similar to that of an environmental management system (EMS), but with a clear emphasis on energy use. An EnMS can be based on a standardised or customised format. 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 (e.g. ISO 50001) or registration to EMAS (when the EnMS is a module of a broader EMS according to the EMAS Regulation).

In addition, established EnMS support companies in complying with the European Energy Efficiency Directive, which obliges companies that are not SMEs to conduct a regular energy audit if no certified EnMS is in place. For SMEs, the Directive aims at establishing national incentives for energy audits (European Commission, 2013b).

In order to establish or maintain a comprehensive and advanced EnMS, several aspects need to be considered and included. The following list contains the main elements of such an EnMS (based on ISO 50001, Carbon Trust, 2013, RKW Hessen GmbH, 2015).

19 For example, see: BEMP on optimal lighting, BEMP on efficient use of compressed air systems, and BEMP on reduction of standby energy of metal working machines.

20 Energy management is also addressed by other BREFs, see BEMP 2.7.

Organisations can reach the best environmental performance when integrating into their EnMS the following aspects.

- **Energy policy and strategy**: The first step is the commitment of a company to manage and monitor its energy use. Establishing an energy strategy involves setting out how energy will be managed and defining the goals. The strategy needs to contain an action plan of tasks, which will initially involve understanding the organisation's current position and establishing the management framework. It is best practice to have energy policy and a detailed action plan in place and review them regularly.

- **Senior management commitment and responsibility**: Gaining active commitment from senior management is utterly important as without such support the effectiveness of the energy management plan is likely to be compromised. Clear responsibilities for energy use must be allocated, e.g. enterprises can have a dedicated internal or external energy manager. Resources in terms of time and budget should be clearly allocated to energy efficiency measures (e.g. dedicated working time share, annual lump sum, reinvestment of the savings; see also investment and budget)

- **Target setting**: To improve energy performance it is important to define challenging but achievable targets that are determined through detailed analysis of energy data at process level and e.g. benchmarking against internal or external performance. For instance, the detailed mapping of the energy use of single carried out processes is essential in order to retrieve process data. These can then further be assessed in order to improve process performance and set targets as well (at the process level).

- **Performance measurement and assessment**: Identifying energy savings is an ongoing process which is followed by the detailed energy monitoring and analysis to determine potential opportunities for saving. Depending on the scope and targets, measurements may be conducted per fuel type and/or per individual machines, units, processes or buildings. This process starts with an initial review to understand the drivers for energy use and costs and leads to a continuous/regular (or periodic) monitoring and performance assessment, which can be supported by the use of e.g. smart meters. The energy use is measured at the process level in order to allow improvements and actions and eventually setting (or revising) of targets. For high energy using processes, a higher priority for monitoring and when setting targets can be given. The existence of new innovative technologies, less energy using, must be taken into account during the assessment stage. Comparing the performance with the targets and adjusting these to the current situation and needs can be done on a regular basis together with the identification of further optimisation potentials. Additionally, the energy (flow) mapping can also be compared against the installed capacity in the manufacturing facility in order to monitor (and potentially) to measure energy savings.

- **Communication**: Employee engagement and communication across the organisation are important parts of developing an organisation's culture of energy efficiency. Without it, energy management becomes easily marginalised and undermined. Best practice includes communication within the company (see also staff training below) and an extensive external communication of energy issues (status quo, targets, measures, achievements) to the company's customers and the society.

- **Staff training**: To raise awareness for and understanding of the targets and measures among employees and to engage them actively, training on energy efficiency and carbon reduction can help change behaviour in the workplace, identify further reduction potentials and reduce unnecessary energy use. Best practice requires proactive staff engagement to identify energy savings potentials.

- **Investment and procurement:** 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 and needs to be integrated into all procurement procedures.

Table 2.5 shows how best practice measures can be distinguished from good practice and fair practice, when considering each of the above aspects.

Table 2.5. Energy management matrix

Practices	*Best practice*	*Good practice*	*Fair practice*
Energy policy and strategy – 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.
Senior management commitment and responsibility	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 and assessment	Continuous/regular performance measurement for each process and assessment against energy strategy and action plan.	Weekly performance measurement for each process, unit or building.	Monthly monitoring by fuel type.
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.
Staff 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.
Investment and procurement	Resources routinely committed to energy	Same appraisal criteria used for	Low or medium cost measures considered

Practices	*Best practice*	*Good practice*	*Fair practice*
	efficiency. Consideration of energy consumption in all procurement and with by applying life cycle thinking.	energy efficiency as for other cost reduction projects.	only if payback period is short.

Target setting can 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 alternative to certification according to ISO 50001, an EnMS can be a module of an EMS, e.g. verified according to EMAS. Adherence to these standards will allow energy management efforts to be officially certified and recognised.

Achieved environmental benefits

The environmental benefits encompass the reduced demand for primary energy sources and the reduction of GHG emissions that are associated with energy generation from fossil fuels such as coal, oil or natural gas.

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.

Appropriate environmental indicators

The appropriate indicators for this BEMP are presented below.

- Energy use per manufactured product (kWh / kg finished product or per manufactured part)
- Energy monitoring system at process level (Y/N)
- Budget allocated to all energy efficiency improvements with return on investment up to five years (€/yr)

Cross-media effects

There are no reported cross media effects for this specific BEMP.

Operational data

This BEMP includes all the important and relevant elements of an EnMS. The reader can find below two specific examples from the implementation of an EnMS. Additionally, below are listed the linked BEMPs of this report:

- 3.1 Efficient ventilation;
- 3.2 Optimal lighting;
- 3.3 Environmental optimisation of cooling systems;
- 3.4 Rational and efficient use of compressed air systems;
- 4.4 Reduction of standby energy of metal working machines;
- 4.6 Multi-directional forging
- 4.7 Hybrid machining as a method to reduce energy consumption;
- 4.8 Use of predictive control for paint booth HVAC management;

Case study: Kreck Metallwarenfabrik GmbH, Germany

In 2010, Kreck Metallwarenfabrik GmbH, a sheet metal forming enterprise implemented an EnMS according to ISO 50001. They achieved at a medium-term a reduction of the energy demand of approximately 30%. The EnMS identified large saving potentials in compressed air and heat generation as well as in lighting. Constant monitoring of energy use was conducted and the company invested in a new compressor unit including heat recovery. In 2012, gas consumption was reduced by 10% and electricity consumption by 20% compared to 2007, despite a 10% increase in production. Staff training on reduction of idle and standby times, efficient heating and ventilation as well as lighting contributed to the good results (RKW Hessen GmbH, 2015).

Case study: Industrial Barranquesa, Spain

Industrial Barranquesa is a Spanish company which produces steel pipe components and flanges for wind towers. They implemented an EnMS in order to monitor the energy use of the manufacturing site. Additionally, workers' knowledge about energy management was enhanced through appropriate trainings. After the training and the implementation of the monitoring process the energy use was assessed, including peeks and consumption rates during public holidays and non-productive days (Industrial Barranquesa, 2017).

The assessment showed that the gas-fuelled ovens for heat treatment and bending of steel and the lighting were processes and operations where significant savings could take place. Thus, the company investigated on the best strategy to heat up the oven with different ways by carrying out various experiments and tests. Thanks to the energy monitoring and investigation, the company reduced its energy use by 5%. In a second step, waste heat was recovered by means of a heat exchanger that takes the heat from the exhaust gas and heats up the air inflow in the combustion chamber, which required changing the burners and adjustments on the regulation of the air flows. With this measure, Industrial Barranquesa could save an extra 10%. Regarding lighting, the company shifted gradually towards LED lighting, resulting in reduction of 15% of its energy use (DEXMA, 2017 and Industrial Barranquesa, 2017).

Applicability

This BEMP is suitable for all companies of the sector, including SMEs. However, the scope of an EnMS depends on the size, ambitions and goals of each company.

Knowledge about innovative technologies or options to improve energy efficiency may present a barrier especially to SMEs.

Improper integration of the aspects of the EnMS and weak communication across the organisation can downgrade the performances of the EnMS in place.

One of the main limitations of implementing some elements of this BEMP as well as some of the energy saving actions that can result from implementing this BEMP is their low ROI. Pay back times are sometimes long, even when the investment costs are low (e.g. for the installation of monitoring tools).

Economics

As it was stated in the applicability section too, the costs for energy efficiency measures as well as their payback times can vary significantly, depending on their type and the degree of energy efficiency in an organisation.

For the company Kreck Metallwarenfabrik GmbH the investment of approximately 20,000 Euros into the EnMS payed off in 2 to 5 years, which is mainly due to the reductions in electricity and gas consumption (operating costs). Detailed examples for the economics of specific energy efficiency measures are available for the respective BEMPs (e.g. BEMP 3.1 on efficient ventilation or BEMP 4.4 on reduction of standby energy).

In case of refurbishment or a new production line, it is important to look into the total lifetime cost rather than to investment costs only. Appraisal of investments can be made on a whole life-cycle basis in order to account for higher initial investment costs that save energy and costs on the medium to long term. This is particularly important for procurement procedures. Energy efficiency shall be integrated into procurement policy of machines, equipment, buildings and devices as well as in actual energy procurement.

Driving force for implementation

The drivers for energy efficiency are numerous, they include:

- Reducing energy costs;
- Reducing greenhouse gas emissions (which may also be associated with specific taxes/levies/permits);
- Reducing emissions;
- Improving process efficiency;
- Improving working conditions and staff engagement;
- Improving public image.

Reference organisations

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Industria Barranques, a Spanish company producing pipes components and flanges for wind towers from metals, http://www.dexmatech.com/es/eficiencia-energetica-industria-grupo-3e/ and http://barranquesa.com/

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2.4 Environmentally sound and resource efficient management of chemicals

SUMMARY OVERVIEW

BEMP is to optimise the amounts of chemicals used for manufacturing processes, minimise the chemicals that are disposed of and substitute hazardous chemicals wherever possible with more environmentally friendly alternatives.

To achieve these aims, fabricated metal products manufacturers can implement the following measures:

- reviewing the current chemical use and management on-site;
- monitoring the chemical use at the level of individual chemicals (and not several chemicals together) and focusing on the most important chemicals used;
- reducing the chemical use wherever possible, e.g. by changing manufacturing processes, using the chemicals more efficiently, adopt business models that align incentives between chemical suppliers and users to incentivise the reduction of chemical volumes;
- replacing hazardous chemicals and substituting with alternatives with lower environmental impact;
- reducing chemical waste and outflows, e.g. by reusing or recycling chemicals; where relevant, using external expertise, such as through partial or total outsourcing of chemical management.

Relevant stages

Cross-cutting	Optimisation of utilities	Manufacturing

Main environmental benefits

Resource efficiency	Water	**Waste**	**Emissions to air**	Energy and climate change	Biodiversity

Environmental performance indicators

- For individual chemicals used, amount of chemical applied (kg / kg finished product or manufactured part) and its classification according to Regulation 1272/2008 (CLP Regulation)

- Amount of chemical waste generated (kg / kg finished product or manufactured part)

Applicability	The BEMP is broadly applicable by all type of companies of the sector, including SMEs. The operation of the described chemical management system requires some technical knowledge, which may be an important barrier, especially for the SMEs.
Benchmarks of excellence	Regular (at least once a year) review of the use of chemicals to minimise their use and explore opportunities for substitution
Related BEMPs	2.1, 2.7, 4.1, 4.2

Description

Companies in the fabricated metal products manufacturing sector apply a variety of different chemicals in their manufacturing operations. Typical examples include:

- Machine or hydraulic oils
- Coolants, lubricants and lubricoolants as cutting fluids

- Solvents or other cleaning agents, e.g. for degreasing
- Chemicals for various coating processes, e.g. corrosion inhibitors or paints

When not managed and handled correctly, these chemicals pose a risk to the health and safety of workers and to the environment due to their often hazardous properties. It is thus of the utmost importance for fabricated metal products manufacturers to have proper chemicals management systems and actions to mitigate risks and minimise environmental impacts in place.

Legal requirements in the EU (e.g. REACH[21] and CLP[22] Regulations) oblige companies that use chemical substances or mixtures for instance to consider the risk reduction measures included in Safety Data Sheets (SDS) of the chemicals and advise the workers using the chemicals, inform their supplier if these are not appropriate or if new information about the hazard characteristics is available and comply with the communication obligations for substances of very high concern (SVHC).

This BEMP goes beyond the sheer correct handling and storage in compliance with legislation requirements. It aims at minimising the amounts of chemicals used and disposed of as well as substituting hazardous chemicals wherever possible. Aspects such as life cycle impacts of chemicals (e.g. resource use, waste generation) and energy or other auxiliaries demand are also taken into consideration in BEMPs 2.1 and 2.2.

Best practice for chemical management in a fabricated metal products manufacturing company consists of the following actions:

- **Review / audit current chemical use and management**, including chemical inputs (materials, quantities, suppliers), points of use, chemical waste generated, disposal methods, documentation and tracking systems, as well as procurement arrangements;
- **Monitor chemical use** at the level of the individual chemicals and avoid monitoring several chemicals used together. The objective of this action is to focus on the most important chemicals applied in the various manufacturing processes.
- **Reduce chemical use** where possible, for instance by optimising their use in processes, reducing the number of references and suppliers or implementing new business models and approaches that incentivise the reduction of chemical volumes;
- **Replace chemicals** and substitute with alternatives having a lower environmental impact;
- **Reduce chemical waste and outflows** e.g. by recovering them after their process use, by cleaning/purifying those that can be recycled, and consider whether this can be done on-site or off-site or outsourced;
- **Assess alternative solutions** to chemical management i.e. partial or total externalisation of chemical management solutions, by applying e.g. chemical management services.

In some cases, outsourcing some of the functions of chemical management will allow optimising its impact and maximising environmental benefits as interests and responsibilities are better aligned.

The following paragraphs describe each of the above mentioned actions.

[21] Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)

[22] Regulation (EC) No 1272/2008 of the European Parliament and of the Council on classification, labelling and packaging of substances and mixtures, amending

1) *Review and audit of chemical use and management*

Continuous improvement of company level chemical management starts with creating a structured information base. It involves systematically identifying all chemical inputs and outputs, understanding activities where chemicals are used and located, monitoring/reporting measures, knowing who is involved and responsible. It also covers external activities influenced by the company business, ranging from the products and services the company procures, to the products and services that the company is providing to its customers. In most fabricated metal products manufacturing companies chemical management is mainly related to e.g. lubrication, cooling, coatings of tools and/or products.

2) Monitor chemicals use

Manufacturers can monitor the chemicals used in the manufacturing site individually. The main aim is initially to focus on the most important chemicals used and avoid monitoring several chemicals used together. This action allows manufacturers to understand the actual amount of chemicals used and for which manufacturing processes. Getting this kind of information, strategies for reducing and/or substituting certain substances or chemicals can then be considered and implemented.

3) *Reduction of chemical use*

Specific measures or practices can be implemented to reduce the amount of chemicals used in the manufacturing sites. For instance, in order to reduce (or optimise) the amount of lubricoolants used, companies can implement cryogenic cooling or high-pressure lubricoolant supply (see BEMP 4.2 for further information).

In addition, a rationalisation of chemical use and purchase (e.g. ensuring that a chemical used in various processes or fabrication units is sourced from a single supplier to better track its use, cascading use of chemicals in several applications) can also yield efficiency gains.

Shifting towards an alternative business model where payments for chemicals are based on functional units instead of volumes can also foster the reduction of chemicals. This is known as *Chemical Leasing* and is explained in more detail in the Operational Data section.

4) *Substitution of chemicals*

In many cases, significant environmental benefits can stem from finding suitable alternatives for hazardous chemicals, i.e. less hazardous substitutes for chemicals or technical solutions that dispense with chemicals. An example for the latter measure is the substitution of applying metal working fluids by implementing a dry cutting process. Any substitution needs to consider both reducing the risks to human health and the environment and the required technical specifications of the fabricated products. Thus, a thorough risk assessment is to be conducted prior to introducing a new substance or process.

5) *Reduce chemical waste*[23]

After the above solutions have been implemented, a minimal amount of chemical may remain that has to be disposed of or treated. In order to reduce the amount of chemical that becomes waste, reprocessing solutions can be investigated e.g. whether the chemical can be reprocessed or purified on site for its re-use, e.g. distilling solvents for metal parts cleaning. In terms of environmental impacts, there may be a trade-off between e.g. the economies of scale of sending the chemical for reprocessing in a centralised unit vs. the transport impacts and spillage risks of sending large amounts of

[23] As chemical waste are considered the non-used chemicals and all the tools or residues from the manufacturing processes that are contaminated with chemicals.

commodity chemicals back and forth to the manufacturing site. Manufacturers need to examine the above mentioned trade off and go ahead with the most efficient solution that improves the environmental performance of the manufacturing site.

6) *Assess alternative solutions to chemical management*

Outsourcing of chemical management and services may take different forms, from purchasing certain services (e.g. Safety Data Sheet maintenance, degreasing of parts at another company) to the complete outsourcing of the management for the process chemicals used throughout a plant (this is known as Chemical Management Services – CMS[24] – and it includes procurement, documentation, waste management, etc.). Specialised companies exist that perform different degrees of chemical management and solutions for the fabricated metal products manufacturing sector, including full CMS. A CMS may have overlaps with the Chemical Leasing concept; however, Chemical Leasing does not necessarily entail the shift of ownership of the chemical and the service is still conducted at and by the user supported by knowhow of the supplier.

Overall, all of the above actions can be implemented either by company's internal resources or by external service providers.

Achieved environmental benefits

Reducing or eliminating the application of certain chemicals in the manufacturing process of metal products can lead to a variety of environmental benefits. Benefits are reduced resource consumption in the company as well as in the upstream production chain, a reduction of the amounts of waste generated and pollutants emitted, and more broadly lower risks for environment and health. Indirectly, this leads also to reduced greenhouse gas emissions.

Calstone, a small company in Canada, which fabricates metal furniture products for offices or workshops, reduced the amount of chemicals for degreasing metals by 60% due to the installation of a vapour spray system in the degreasing process, which eventually resulted in optimised chemical use (OECD, 2017).

Service-oriented business models such as Chemical Leasing lead to a more efficient use of the chemicals. This in turn induces the amount of chemicals used and disposed of. For instance, applying these business models, the company SAFECHEM and PERO Innovative Services GmbH reduced the amount of chemicals by over 70% for the cleaning of metal parts for the automotive industry. The reduction rates of the associated waste (e.g. filter material and solvent) were in the range of 40% to over 80%. Other important benefits of Chemical Leasing are:

- Reduction of energy use (directly in the process, e.g. due to less cleaning cycles, and indirectly due to the smaller amounts of chemicals that need to be produced); for the abovementioned application 46% and 76%, respectively;
- Reduction of water use, e.g. due to process optimisation and/or more efficient chemicals;
- Stimulation of substitution of hazardous chemicals;
- Knowledge enrichment, needed to optimise the processes in order to reduce the consumption of chemicals;
- Reduction of the quantity and frequency of deliveries and associated packaging waste (pallets, shrink wrap, etc.);
- Avoidance of underutilized chemicals, especially among small to mid-sized companies;

Service-based business models have also been applied for galvanisation in order to improve the waste treatment of acids that are required during pre-treatment. The optimisation of this process resulted in enhanced reusability of the acid, reduced waste

[24] CMS are further explained in the operational data section of this BEMP.

amounts that require treatment and the possibility to reuse the substance in another process (Velpen, 2017).

The substitution of chemicals based on fossil resources with renewable alternatives has possibly a positive impact on the environmental performance. For example, when replacing crude oil-based lubricoolants with rape seed oil-based ones, the energy demand particularly over the whole life cycle of the product can be improved. This leads to related reductions in greenhouse gas emissions. However, the endurance of the renewable lubricoolant needs to be taken into account and may strongly influence the result (VDI ZRE, 2017).

Appropriate environmental performance indicators

The appropriate indicators of this BEMP are listed below:

- For individual chemicals used, amount of chemical applied (kg / kg finished product or manufactured part) and its classification according to Regulation 1272/2008 (CLP Regulation)

- Amount of chemical waste generated (kg / kg finished product or manufactured part)

Cross-media effects

There are no general cross-media effects associated with an environmentally sound chemicals management but different effects may occur depending on the type of management. Certain measures such as the substitution of chemicals may adversely affect the consumption of energy or water in the application itself or indirectly over the lifetime of the chemical substance (e.g. when renewable oils as basis for lubricants require more energy for their processing). On the other hand, the introduction of service-oriented business models such as Chemical Leasing may not only decrease amounts of chemicals and the risk posed by them but can simultaneously lead to savings of energy and/or water due to the optimisation of processes.

If chemicals are transported from the user to an external contractor for recovery and back for re-use, additional environmental impacts may result from the transporting that need to be considered.

Operational data

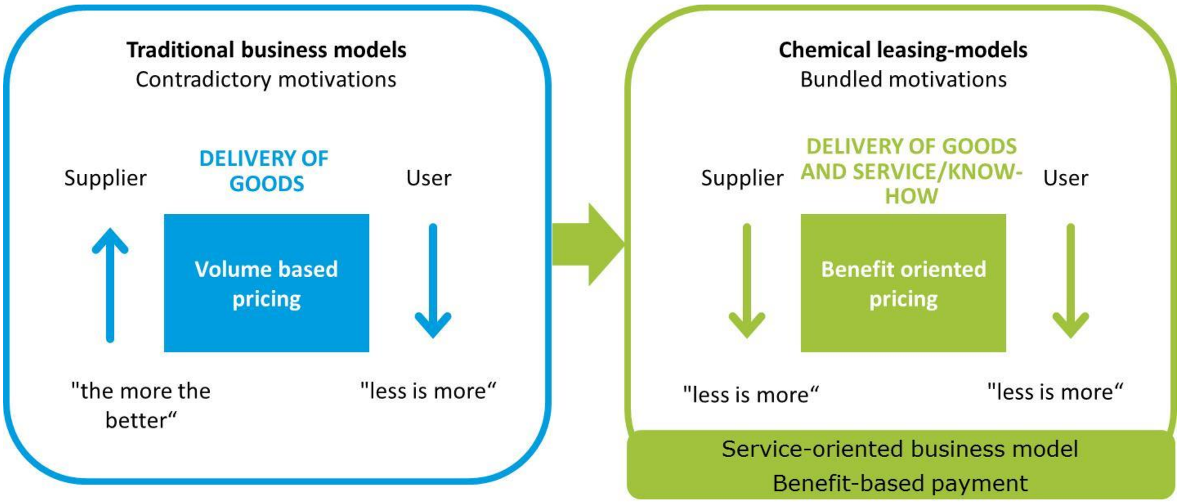
To ensure that chemical management is optimised as processes evolve the six actions presented in the Description section can be repeated on a regular basis.

Chemicals management for the metal fabricating sector can be outsourced to specialised companies. For specific services such as metal parts degreasing or galvanisation often small dedicated companies exist that perform the required service.

Chemical Leasing

Instead of the conventional business model of buying, using and disposing of chemicals, companies can partner with their suppliers and purchase the service or function rendered by the chemical. From a supplier's perspective there is a shift from the idea of providing/selling the chemicals towards the idea of providing the functionality. With Chemical Leasing, the suppliers will sell e.g. square meters of cleaned surface or number of parts cleaned instead of a certain quantity of cleaning chemicals. From a user's perspective, Chemical Leasing may lead to reduced costs and higher resource efficiency if the chemicals are used more efficiently, as well as reduced risks for environment and health, while maintaining or optimising the quality and reliability of the process. An important aspect of Chemical Leasing is that suppliers and users become partners with common incentives or targets (Figure 2.15). The supplier may also become responsible for recycling or disposal of the used chemical, which aligns the interest and responsibilities between the production and end-of-life phase. Within the Chemical Leasing business model, suppliers and users share the generated cost benefits that are triggered by a reduction of energy use, resource efficiency and/or process optimisation. Companies offering Chemical Leasing provide also their knowledge to select chemicals and technologies with the best technical, environmental and health performance for the specific application (UNIDO, 2017). In this way, Chemical Leasing also fosters substitution of hazardous chemicals. Examples of typical applications of Chemical Leasing in the fabricated metal products manufacturing industry are surface treatment processes such as degreasing (e.g. automotive or aerospace industry) and coating (e.g. white goods).

Figure 2.15. Compared to the conventional business mode, Chemical Leasing aligns the incentives of supplier and user of the chemical



Aircelle Ltd, manufacturer of engines and components for the aerospace industry, implemented the Chemical Leasing technique. Initially, the company changed its cleaning equipment. The new equipment operates under closed, vacuum conditions. Emissions of chemicals stay below 1 ppm. Consumption of solvents was reduced by this new equipment as well. The services provided resulted in a 10% reduction of solvent consumption. In addition, the machine utilisation went up to 99%, due to a better (more stable) supply of chemicals. Compared to the initial situation, the company's annual solvent consumption dropped by about 93%, and a reduction of energy cost by 50% was also realized.

Other examples of successful Chemical Leasing applications in the fabricated metal products manufacturing sector are e.g. metal parts cleaning in Serbia (UNIDO, 2016a) and powder coating in Egypt (UNIDO, 2016b).

At BAE Systems (Samlesbury, UK) Chemical Leasing and new cleaning equipment led to a solvent reduction (trichloroethylene) from 5 tonnes to less than 0.5 tonnes per annum (i.e. a 90% reduction) (SAFECHEM, 2012).

Chemical Management Services (CMS)

Although there is no exact definition of CMS, the concept is that the supplier of a chemical offers a series of chemicals related services together with the chemicals. These services may include chemical inventory, pollution monitoring, maintaining safety data sheets (SDS), personnel training, laboratory works, etc. The range of chemical management services varies considerably.

CMS is often a good start for small scale experiments with chemical as a service. A good way to start with CMS is (based on Chemical strategies partnerships, 2015):

- Inventorise processes using chemicals: list chemical usage processes, amounts and related costs;
- Look for partners based on processes, type of chemicals, amount of chemicals and related cost;
- Set a baseline for chemical costs: mapping of life cycle stages, chemicals flow in the company and associated costs;
- Develop an action plan: prioritisation of products and processes, case studies (scenario analysis), identification of performance measures;
- Further engage partners: stakeholders analysis, service providers, business case, definition of roles and responsibilities.

Reduction of chemical use (process improvement)

The small Canadian company Calstone is a manufacturer of metal furniture products and implemented a variety of measures over the last decade to improve its environmental performance. Amongst others, their efforts for improved environmental performance resulted in a reduction of chemicals for degreasing metals by 60% due to the installed vapour spray system in the degreasing process (Calstone, 2012).

Applicability

All companies of the sector need to have a chemical management system in place that allows the company to document, store, handle and apply chemicals in accordance with the relevant laws and regulations. This BEMP can thus be applied to all types of companies in this sector, including SMEs.

Any company of the sector using chemicals can conduct the first actions mentioned in the Description section of this BEMP, i.e. review their chemicals management and find options for improvement of chemical use and reduction of chemical wastes. Finding suitable substitutes for chemical substances in a certain process might require detailed technical understanding and knowledge and is very much dependent on the process, e.g. lubrication or cooling. Therefore, this may be a barrier especially for SMEs.

Chemical Leasing is possible in companies of all sizes but requires an in-depth management shift supported by top management.

Economics

CMS can significantly reduce the costs associated to chemical procurement, use and waste disposal; in some cases up to 80% (Quaker, 2017), whereas a total average cost reduction, around 30% can be achieved the first five years (EPA, 2012). Upgrading an in-house CMS requires costs to enhance internal capacity and develop more sophisticated management system. Contracting an external service provider with the appropriate know-how is a cost effective approach for designing and implementing environmentally preferable purchasing, chemical exchange and other waste minimisation/pollution prevention initiatives.

Payments are based on a functional unit in the case of Chemical Leasing but may be a fixed e.g. monthly fee for CMS (EPA, 2012).

The metal furniture producer Calstone reduced their annual costs by approximately USD 20,000 thanks to the implementation of a CMS. In particular, a variety of measures were applied and a reduction of 60% of degreasing chemicals was achieved (OECD, 2017 and Calstone, 2012).

Driving force for implementation

Several driving forces for the implementation of improved and environmentally sound chemicals management exist:

- Compliance with current and upcoming legislation, including REACH;
- Risk reduction for environment, health and safety (EHS);
- Cost savings (e.g. related to a reduced use of chemicals or disposal costs);
- Improved knowledge about the processes and process optimization;
- Access to new, environmentally aware markets/customers.

Reference organisations

Aircelle Ltd. (Burnley, UK): Aircelle Ltd. is a large manufacturer of engines and components applied in the aerospace industry. They apply Chemical Leasing for cleaning their metal parts.

BAE Systems (Samlesbury, UK): BAE Systems is a large provider of defence and security products primarily for military applications. The company cleans its metal parts under the Chemical Leasing business model.

Calstone Inc. (Canada): Calstone is a small manufacturer of metal furniture products. Chemicals for degreasing metals have been reduced by 60% due to the installed vapour spray system in the degreasing process (Calstone, 2012)

DHD-technology (DE): DHD-technology produces metal nets for different industries (filtration, textile cleaning, automotive, etc.). They extend the lifecycle of their chemicals in use by use of Chemical Leasing (Chemical leasing, 2015).

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2.5 Biodiversity management

<table>
<tr><td colspan="7">SUMMARY OVERVIEW
BEMP is to take into account direct and indirect impacts throughout the value chain and on-site manufacturing processes, by taking the following actions:
• Assessing direct impacts by conducting a site review and identifying hotspots;
• Conducting an ecosystem management review to identify the impacts of ecosystem services throughout the value chain;
• Working with relevant (local) stakeholders to minimise any issues;
• Measuring impacts by defining and monitoring relevant metrics;
• Regular reporting to share information about the company's efforts.</td></tr>
<tr><td colspan="7">Relevant lifecycle stages</td></tr>
<tr><td colspan="2">Manufacturing</td><td colspan="3">Supply chain</td><td colspan="2">End-of-life</td></tr>
<tr><td colspan="7">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td><td>Hazardous substances</td></tr>
<tr><td colspan="7">Environmental performance indicators</td></tr>
<tr><td colspan="7">- Number of projects collaborations with stakeholders to address biodiversity issues (no)
- If located in or adjacent to protected areas: size of areas under biodiversity friendly management in comparison to total area of company sites (%)
- 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, m²)
- Procedure/instruments in place to analyse biodiversity related feedback from customers, stakeholders, suppliers (Y/N)
- Plan for biodiversity gardening in place for premises or other areas owned, leased or managed by the company (Y/N)
- Total size of restored habitats and/or areas (on-site or both on-site and off-site) to compensate for damages to biodiversity caused by the company (m²) in comparison to land used by the company (m²).</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="5">The BEMP is broadly applicable to all types of companies in this sector, including SMEs.
The implementation of the elements of the BEMP requires commitment from the hierarchy. The direct benefits from the implementation of the elements of this BEMP are not possible to be quantified. Similarly, the calculation of a direct return of investment when applying the elements of the BEMP is not possible as well. These two points can constitute a significant barrier especially for the SMEs.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="5">A biodiversity action plan is developed and implemented for all relevant sites (including manufacturing sites) to protect and enhance the local biodiversity'</td></tr>
</table>

Related BEMPs	2.1, 2.2

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.

Biodiversity is not considered 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.

Companies operating in the metal product manufacturing sector impact biodiversity either directly through their own core activities (e.g. the land footprint that they occupy and may displace or disrupt natural habitats) or throughout their value chain. Impacts on biodiversity typically occur upstream through the extraction of raw materials, downstream through the use of metal products, as well as in transport.

Best practice in the management of biodiversity shall take into account both direct and indirect impacts throughout the value chain and own operations, by implementing the following actions:

- Conduct an **ecosystem management review** so that the impacts of ecosystem services throughout the value chain can be clearly understood, and to work with relevant stakeholders to minimise any issues. In addition, the manufacturers can assess the direct impacts within the manufacturing site on biodiversity by conducting a site review and identifying the hotspots;

- **Measuring impacts** by defining and monitoring relevant metrics which reflect actions on biodiversity. The first step in the measurement of the impacts on biodiversity requires a good understanding of how an organisation creates positive and/or negative impacts on biodiversity. Accurate information on land use, environmental impacts and protectable species is essential for individual manufacturing locations before actions can be planned and taken. Frontrunner organisations often introduce extensive measurement activities at all of their manufacturing 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).

- Collaborating with (**local) stakeholders** e.g. academics, agencies or NGOs with good knowledge of the natural habitats and ecosystem services potentially affected. The main goal is to manage the manufacturing site properly to promote and maintain biodiversity, and implement actions to minimise impacts. Additionally, working in partnership with specialist organisations involved in biodiversity and educating staff and contractors in the importance of protecting and enhancing biodiversity;

- Regular **reporting** to share information with stakeholders about the organisations' efforts in relation to biodiversity.

Additional actions on how to put in practice the key principles outlined above are described in the **Guidelines** produced by the Global Nature Fund and Lake Constance Foundation in partnership with the European Commission (LCF/GNF 2016). These guidelines give inspiration to the companies on how to embed biodiversity actions into the environmental management systems of the organisations.

Achieved environmental benefits

Achieved environmental benefits must be considered in terms of their ability to reduce indirect and direct impacts on biodiversity, thereby increasing the conservation of natural resources, and associated biodiversity and ecosystem service provision (Hörmann, personal comm., 2014 and LCF/GNF 2016).

Daimler, an automotive manufacturer which produces metallic parts and components has implemented a series of actions to promote biodiversity on-site e.g. making areas suitable for use as habitats as well as by nesting and colonization aids. In this company, they listed all the achieved benefits which among others were the full documentation of hazardous waste and the systematic restoration of degraded areas to improve the food supply for native species (Gaudillat et al., 2017).

Appropriate environmental indicators

The following set of basic key indicators can be used by all type of companies, including SMEs:

- Number of projects collaborations with stakeholders to address biodiversity issues (no)
- If located in or adjacent to protected areas: size of areas under biodiversity friendly management in comparison to total area of company sites (%)
- 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)
- Procedure/instruments in place to analyse biodiversity related feedback from customers, stakeholders, suppliers (Y/N)
- Plan for biodiversity gardening in place for premises or other areas owned, leased or managed by the company (Y/N)
- Total size of restored habitats and/or areas (on-site or both on-site and off-site) to compensate for damages to biodiversity caused by the company (m^2) in comparison to land used by the company (m^2)

In addition, the companies of the sector can consult the indicators suggested by the Business & Biodiversity campaign and the Global Nature Fund / Lake Constance Foundation guidelines. These indicators are compatible with the requirements of EMAS and ISO14001 so that biodiversity can be more easily incorporated into existing management systems (LCF/GNF 2016).

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.) (Gaudillat et al., 2017).

Operational data

Conduct an ecosystem management review

The first step is to understand whether and how operations and manufacturing processes impact biodiversity. The second step is to take action by implementing relevant actions and measures to promote and maintain biodiversity at the manufacturing site and throughout the supply chain.

Manufacturers typically 'screen' their business operations and manufacturing processes to identify links to biodiversity. Practical actions and measures that manufacturers typically implement (both at their manufacturing sites and throughout supply chain) are the planting of native vegetation, natural ponds or beehives to attract pollinators, staff trainings and seminars.

Measurement

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

- Conversion or destruction of habitats, e.g. land conversion resulting from site development.
- Pollution where 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, which 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 following existing guidelines. For example, biodiversity checks are offered as part of European Business and Biodiversity Campaign. They provide 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). 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.

Collaboration with (local) stakeholders

The companies usually carry out voluntary biodiversity conservation measures. These measures range from relatively simple actions such as tree planting to more complexes e.g. implementation of integrated biodiversity conservation projects including for instance environmental education programmes for staff. Other frontrunner companies have set up systemic collaboration with stakeholders and NGOs to ensure that the proper actions to promote and maintain biodiversity are being implemented.

Regular reporting

Reporting is critical to making the most of the reputational benefits of implementing biodiversity measures, as well as sharing information to encourage environmental protection. In order to ensure reporting is effective, manufacturers can (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 indicators of this report or the GRI Environmental Performance Indicators) which specify the common information to be reported, as well as company-specific biodiversity indicators.

For further details on what to report, how to report and what indicators to use when reporting on biodiversity, companies can also 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 for the latest guidance.

Specific examples from companies who have implemented biodiversity conservation measures on-site along the above mentioned series of actions can be found in the **Best Practice report for the Car manufacturing sector** (Gaudillat et al., 2017).

Applicability

The BEMP is applicable for all type of companies of the sector, including SMEs. However, it is more suitable for new built manufacturing sites, since in existing sites the availability of free space may be limited. Nevertheless, manufacturers shall know that even in sites with little or no open space available for new development, it is feasible to implement some solutions e.g. green roofs in already constructed surfaces.

This BEMP requires commitment from the hierarchy since it is particularly difficult to calculate the actual ROI. Therefore, this difficult quantification of the environmental benefits of the BEMP constitutes a challenge for the manufacturers since it would require some effort to be convinced about the implementation of the measures/actions of this BEMP.

Economics

The economic importance of intact nature is often overlooked or underestimated (Global Nature Fund, 2013; Gaudillat et al., 2017). 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 reporting and measurement allow manufacturers 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).

Driving force for implementation

Companies may anticipate that biodiversity 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 industry also include (Business Biodiversity, 2011; Gaudillat et al., 2017):

- 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.

Reference organisations

Daimler: implemented measures/actions to promote biodiversity on manufacturing sites.

Global Reporting Initiative: guidelines and instructions on how organisations and companies can report on the protection of the biodiversity.

Lake Constance Foundation and Global Nature Fund: Organisations which have produced guidelines on how to protect biodiversity through environmental management systems.

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2.6 Remanufacturing and high quality refurbishment of high value and/or large series products and components

<table>
<tr><td colspan="6">SUMMARY OVERVIEW
Remanufacturing involves dismantling a product, restoring and replacing components and testing individual parts and whole product to ensure that meets the same quality standards as new products manufactured nowadays accompanied with an appropriate warranty. Refurbishment refers to used products that met their original quality standards when it was first introduced in the market i.e. the refurbished product achieves the quality standard level that was in place when it was firstly manufactured and actually not the one of the same product produced nowadays.
BEMP is to take into account and enable opportunities for remanufacturing or refurbishment of used fabricated metal products and bringing them into the market for reuse, when environmental benefits are proven under a full life cycle perspective. The remanufactured or refurbished products shall achieve at least the same quality levels they had when they were first introduced in the market and are sold with the appropriate warranty.</td></tr>
<tr><td colspan="6">Relevant stages</td></tr>
<tr><td colspan="2">Cross cutting</td><td colspan="2">Optimisation of utilities</td><td colspan="2">Manufacturing</td></tr>
<tr><td colspan="6">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td></tr>
<tr><td colspan="6">Environmental performance indicators</td></tr>
<tr><td colspan="6">• Percentage of saved raw material used for remanufacturing/refurbishment compared to producing a new product (kg of material to remanufacture/refurbish / kg of material for new product)
• Avoided CO_{2e} emissions associated with remanufacturing/refurbishing a product compared to producing a new one (CO_{2e} emissions remanufacturing/refurbishing / CO_2 emissions new product), specifying if scope 1, 2 and/or 3 are included</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="4">The BEMP is applicable to all types of companies in this sector, including SMEs.
Remanufacturing or refurbishment may increase companies' operational costs, which are certainly outbalanced for manufacturing of high value products/components/parts and for large volume series.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="4">The company is offering remanufactured/refurbished products with LCA verified proven environmental benefits</td></tr>
<tr><td colspan="2">Related BEMPs</td><td colspan="4">2.1, 2.2</td></tr>
</table>

Description

Refurbishment and remanufacturing are important components of a resource efficient manufacturing industry and represent key strategies for the implementation of a circular economy[25] (see also BS 8001[26]). Remanufacturing and refurbishment can be considered

[25] For further information on the integration of the circular economy approach in the companies' business models, please see BEMP 2.1.

[26] BS 8001, The world's first standard for implementing the principles of the circular economy in organisations; https://www.bsigroup.com/en-GB/standards/benefits-of-using-standards/becoming-more-sustainable-with-standards/Circular-Economy/

as a “loop” of the circular economy, where products return to a manufacturing setting where most of the value can be recovered by suitable remediation techniques (The Scottish Government, 2015).

Refurbishment and remanufacturing are concepts which are applied in various sectors and are currently gaining popularity. The aerospace, automotive components and heavy-duty and off-road (HDOR) industries generally represent the sectors with the most applications. The fabricated metal products manufacturing sector instead, does not have so many developed applications nowadays. Nevertheless products/parts/components fabricated for other sectors e.g. aerospace and automotive are examples that fit very well to the fabricated metal products manufacturing sector (ERN, 2017).

Remanufacturing involves dismantling a product, restoring and replacing components and testing individual parts whereas the whole (remanufactured) product ensures that meets its original design specifications. The performance after remanufacturing is expected to be the same as the original performance specification. Moreover, the remanufactured product generally offers a warranty equivalent or better than that of a newly manufactured product (ERN, 2017; VDI, 2017).

Refurbishment ensures that the refurbished product/part/component will be at least “as good as when new”, in terms of performance. Often, it refers to improving aesthetics of a product without systematic verification or improvements of all functionalities.

Remanufacturing is a more thorough process when compared to refurbishing, as it is more demanding and works towards a higher standard. In case a product cannot meet or exceed the original performance specifications, it should be then considered as a refurbished product.

Refurbishment and remanufacturing require several competences and capabilities and close collaboration between involved stakeholders along the supply chain. Working in close collaboration with the involved stakeholders may result in improved business relationships with suppliers and customers. Moreover, companies may need to modify their business models to support remanufacturing activities by offering their customers a range of services beyond the initial sale of products.

From the organisation perspective, the manufacturers who have already integrated the remanufacturing activities into their operations, they can offer a full service portfolio that encompasses various maintenance services as well as total solution service contracts. Typically, the aim of integrating remanufacturing in the business models of the organisations contributes to the increase of the number of products with remanufactured capabilities and the number of possible remanufacturing cycles and to the introduction of eco-designing principles in the various products. This is possible by considering as far as possible the entire life cycle of the products. Therefore, a new business model can be developed, offering various services related to the product remanufacture. Consequently, by offering product along with service activities, the company can achieve revenue growth and profitability (Visnijic and Van Looy, 2013).

Manufacturers can keep in mind remanufacturing options in the earliest phase of product development. This can be done, preferably, already during the design phase of their products in order to eventually allow remanufacturing. Designing for remanufacturing involves adding new performance criteria, considering design for disassembly aspects during the feasibility and planning stage of the project, as well as incorporating new review stages during product development.

Another dimension of the remanufacturing is the storage and sharing of data and information about manufactured products (referring also to specific parts or components). The development of suitable manuals can ensure proper remanufacturing, including remanufacturing by either customers or other companies.

High-quality refurbishment typically focuses on fabricated products of one specific manufacturer and is very often carried out by (or in close co-operation with) the Original

Equipment Manufacturer (OEM). This happens due to the fact that the OEM is the only actor who has available all the information of the product (as regards to its development, design and quality checks). In addition, OEMs have usually established access to the suppliers of original parts and components that might be required for refurbishing activities. Furthermore OEMs have sales specialists and specialised distribution channels to sell the refurbished products.

Generally, remanufacturing and/or high-quality refurbishment activities involve a series of actions ranging from the selection of used devices to service and maintenance activities. These steps are described further in Table 2.6 (Moeller M. et al., 2015).

Table 2.6. Activities for remanufacturing and/or high-quality refurbishing of used products

Step No.	Name	Description
1	Selection	During this step, decisions regarding the type and condition of products for refurbishing are taken. Typically, the selection process is based on criteria related to the types of models, age and condition of products, and possibly also service history and performance. These criteria are used to enable a targeted sourcing and to avoid the purchase of products which will prove unsuitable for high-quality refurbishing.
2	Sourcing	The sourcing is the transaction for transfer of the equipment/product from the owner and/or user to the refurbishing entity. Sourcing mostly includes some form of incentives such as direct payments or trade-in models, the logistics to transport the used equipment/product to a refurbishing facility in a safe manner (e.g. protection against damage), and activities and measures to communicate information on incentives and transaction processes to a target audience. Depending on the type of product, sourcing might also include deinstallation (e.g. necessary for large equipment) and paperwork to comply with legislative requirements.
3	Technical refurbishing	The technical refurbishing encompasses all steps necessary to bring a product back to the original level of functionality, including safety, reliability and aesthetics. This typically includes cleaning and disinfection, the carrying out of necessary repairs, the exchange of individual parts/components, aesthetic refurbishment, system testing and packaging.
4	Sale/Delivery	This step includes all activities to bring the products into (second) use. This includes marketing, sale, delivery and possibly also installation at the customers' premises.
5	Warranty	Remanufacturing also requires technical support, including repair and maintenance within the warranty conditions and periods.

Source: Moeller M. et al., 2015

High-quality refurbishment can require the substitution of certain parts and components of the used products (see point 3 of Table 2.6) and these parts can be replaced with new or refurbished ones. The substituted parts are also refurbished, if and when their condition permits it. The same approach can be adopted during maintenance and repair of the equipment/products: all the substituted parts can be checked and then sent to refurbishment (if suitable). Often, manufacturers of fabricated metal products source (some) items/parts/components of the products they manufacture from different suppliers; therefore, if these items/parts/components need to be refurbished, their actual manufacturers can be involved in the process by agreeing and sending the components to be refurbished.

Achieved environmental benefits

The environmental benefits of this BEMP result from waste prevention and savings by reduced production of new products/parts/components. This results in less use of natural resources and energy and less treatment and disposal of waste. For instance, for the ICT sector, it was reported that over the period 2003 - 2009, the CO_2 emissions were reduced by ten times, thanks to remanufacturing activities (Bitkom, 2015). In other words, the net environmental benefit due to lifetime extension has to be calculated individually, also taking into account energy efficiency gains of new products.

Sundin (2004) indicated that, from a natural resource perspective, remanufacturing is preferable to new manufacturing. With remanufacturing the initial efforts to shape the product parts (usually the most energy-intensive such as melting, casting etc.) are salvaged. Furthermore, it is found that it is environmentally and economically beneficial to have products designed for remanufacturing.

Caterpillar UK-based plant has reported that since 1972 they have achieved a reuse of total 43 million tonnes of core materials and an avoidance of approximately 52 million tonnes of CO2 thanks to remanufacturing activities (Walsh, 2013).

As regards to the remanufacturing of certain metal components for the automotive sector, ERN (2015b) reported that material savings up to 88% can be achieved, when compared to the use of new components. Similarly, 53% decrease of CO2 emissions and 56% lower energy use is achieved, again when compared to the use of a new component for the same application.

Appropriate environmental performance indicators

The appropriate environmental performance indicators for this BEMP are listed below:

- Percentage of saved raw material used for remanufacturing compared to producing a new product (kg of material to remanufacture / kg of material for new product)
- Avoided CO_{2e} emissions associated with remanufacturing a product compared to producing a new one (CO_{2e} emissions remanufacturing / CO_2 emissions new product), specifying if scope 1, 2 and/or 3 are included

Cross-media effects

Case studies show that companies implementing remanufacturing often have problems with material flows, use of space and high inventory levels. This is often due to uncertainties concerning the quality and the number of products for remanufacturing. To overcome these problems, the companies need to implement a better control as regards product design and use phase, including the life cycle phases that precede the remanufacturing process (Sundin, 2004).

From an environmental perspective it is to be noted that remanufacturing might not always represent the most suitable solution and the related benefits need to be evaluated individually for every product. For instance, in case of complex systems (i.e. products with many components) containing hazardous substances it is recommended that only certified companies (preferably) using appropriate equipment in specific licensed places (facilities) and only accurately trained staff conduct disassembly and further treatment operations and that all environmental requirements are fulfilled. Otherwise, remanufacturing might result in emissions of hazardous substances to the environment (e.g. oil to soil and/or water). The same also applies to all kind of waste streams and other residuals which need to be properly disposed of.

Operational data

As indicated by Schaeffler (2017), typical fields of application are bearings of railcars, aeroplanes and wind turbines[27]. Other areas of application are for instance compressors as well as highly complex sectors including robotics. Some examples are illustrated in the case studies below:

Case study SKF (UK) – Industrial bearing remanufacturing service

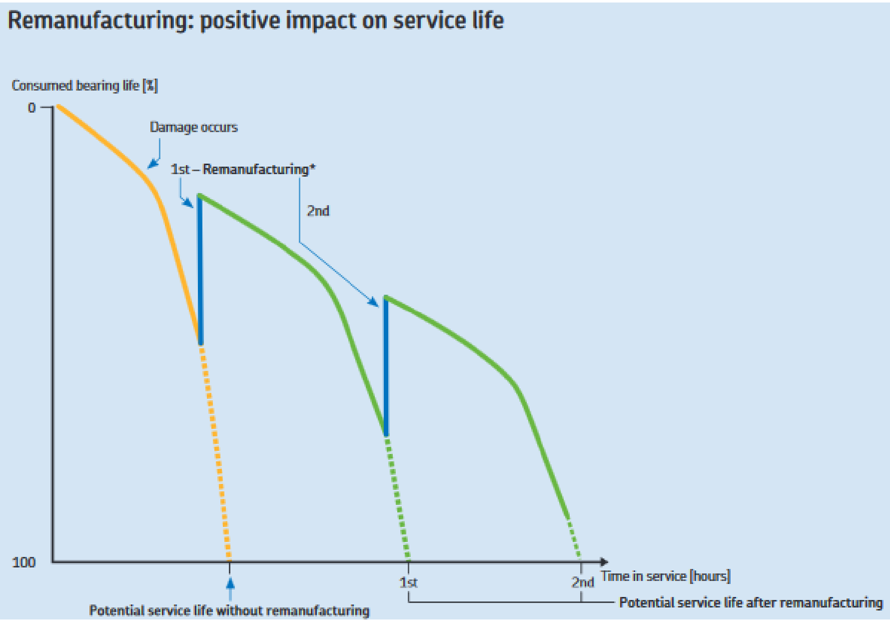
The effective service life of bearings is often shorter compared to the calculated lifetime because of certain application conditions including contaminations and metal-to-metal contact in the rolling zone. The most common damages are wear, rust, indentations and microcracks.

To prevent the failure of bearings, remanufacturing can be applied before a major damage occurs. This can substantially prolong the service life of the bearing, reducing costs and lead times. Moreover, the energy and raw materials use is substantially lower for remanufacturing compared to the construction of new bearings representing thus an environmental benefit.

Depending on the amount of remanufacturing required, up to 90% less energy is used to remanufacture a bearing instead of manufacturing a new one. Furthermore, cost-benefit analyses show that significant economic savings can be achieved depending on bearing size, complexity, condition and price. In addition to reduced energy use remanufacturing services help protect the environment by responsible cleaning of used bearings and appropriate waste management.

Through SKF's remanufacturing processes, relevant functional surfaces are repaired, including, if necessary, the replacement of single components. As a consequence, a much longer service life of the bearing can be exploited, as illustrated in Figure 2.16.

Figure 2.16. Positive impact on service life of bearing remanufacturing (SKF Group, 2014)



[27] The mentioned examples do not necessarily belong to the fabricated metal products manufacturing sector, but are very suitable and relevant for it as well, since they deal with similar industrial processes (e.g. forming, machining).

As the basis for its remanufacturing service, SKF applies bearing manufacturing standards, processes, equipment, quality assurance and knowledge as well as competences. This further includes acceptance criteria to deliver high quality results, also in cases where extensive remanufacturing is needed. Traceability is achieved through an advanced management system that includes the uniquely marking of each asset during the remanufacturing process.

In addition to standard remanufacturing, SKF can bring the bearings to a new or higher specification by mounting sensors, integrating lubrication and sealing solutions as well as rework to other specifications.

Advanced monitoring systems further improve remanufacturing results since they detect failures immediately after their appearance (SKF group, 2014).

Case Study ACES Compressors (UK) – compressor remanufacturing

The company built up a supply system of remanufactured compressors used for refrigeration and air conditioning. In most cases the remanufactured compressors are supplied on an exchange basis where the company supplies a compressor from stock and the defect compressor is returned in exchange, or a surcharge is made. If no specific compressor is available the contractor returns the broken compressor to the company for remanufacturing. Sometimes the remanufacturing is carried out directly on site.

The remanufacturing process includes the following steps. The first step is to drain the oil (lubricants) and to completely strip down the compressor. Then, all components are inspected and measured for size and tolerance using micrometers (Figure 2.17). If it is possible to re-grind the crankshaft and re-bore the cylinder bores these measures are performed directly on site. Parts in good conditions are reused; the remaining ones are replaced according to contract specificities. Valve reeds and piston rings are discarded and all valve plates are surface ground. The stator windings are removed, identified with the compressor and sent to the electrical re-wind department for testing or re-winding. All cast components, i.e. body, heads and end covers are then thoroughly cleaned using a Vaqua wet blaster or degreaser tank. After that, the compressor is reassembled and tested several times, before being spray-painted and replaced on the market.

Figure 2.17. Two steps in the remanufacturing process of compressors

The main challenge of the remanufacturing processes is to source parts for compressors that are no longer manufactured and source specific compressor bodies to replace those that are found to be beyond economical repair or scrapped.

Customers get the remanufactured products as good as newly manufactured with the same warranty. On top of the energy and resource savings, further major environmental benefits arise from an appropriate treatment of waste oils (ERN, 2016).

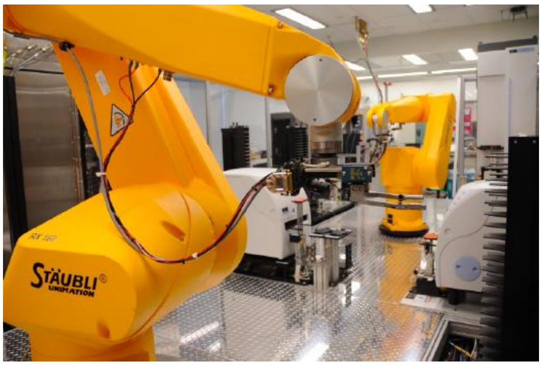
Case study: robotif GmbH (ERN, 2016)

The company mainly remanufactures 6-axis and scara robots but the focus has shifted from standard remanufacturing to improving spare parts during the process. As an example, the wiring harnesses in robots often appear to be worn and available OEM spare parts have the same weak points. Due to that, robotif designed improved wiring harnesses in cooperation with its supplier leading to an increased importance of spare parts.

The remanufacturing process starts with the disassembling and cleaning of the robots. After that, the analysis, the remanufacturing and the reassembly are arranged, including the following steps:

- Complete disassembly of the robot, incl. wrist or quill
- Special tests of all assemblies
- Documentation of all relevant measurement results
- Repainting of the housing parts
- Renewal of all standard rolling bearings
- Replacement of all seals
- Re-assembly
- 24h test run with nominal speed and load

Figure 2.18. Remanufacturing of robots (robotif, no date)



Robotif has developed a detailed documentation and extensive know-how as regards mechanics. For every malfunction, worn part or damage, robotif creates a documentation sheet that step by step leads to the establishment of an important database, containing special information on several robot models (Figure 2.18).

As environmental benefits avoided waste amounts are achieved as well as raw material savings for manufacturing new robots. The improvement of spare parts leads to better performance of remanufactured products but also the development of new robots may be influenced (robotif, no date).

Case study: Atlas Copco, refurbishment of hydraulic breakers (Atlas Copco, 2017)

The company offers a refurbishment programme for the hydraulic breakers. After the refurbishment, the hydraulic breaker is restored back to its original technical specifications. The refurbishment of the breaker is carried out following the listed steps below:

1. seeking for original parts
2. piston and cylinder replacement
3. sandblasting and painting

Applicability

This BEMP is broadly applicable to all types of companies, including SMEs.

It is more suitable for high value products (e.g. bearings for wind turbines), complex and durable, or fabricated in large series / quantities (Schaeffler, 2017).

Automotive sector is one of the sectors that remanufacturing is successfully applied or has a high potential to be applied. In particular, parts manufactured for the automotive sector represent by far the largest opportunity for remanufacturing. Also, products such as heavy duty motors, pumps, compressors, gearboxes, etc., products with high material content and large embodied energy (e.g. casting parts, parts with complex forms, parts with expensive materials, etc.) are very suitable for remanufacturing.

Remanufacturing often requires additional space. This constraint however can be overcome by making use of smart stock solutions or product combinations (ERN, 2015b).

The applicability of this BEMP may be limited due to the lack of detailed information and manuals on third party products, impeding remanufacturing for various components. This leads to a lack of remediation techniques that would be necessary to increase the profitability of the sector and to ensure that remanufactured products reach equal performances as new ones (ERN, 2015b).

Economics

The implementation of remanufacturing and/or refurbishment can lead to cost savings both for the fabricated metal product manufacturer and the consumer. Depending on the product and the intrinsic value of the parts, the savings for consumers can be up to 90%. From the remanufacturer perspective, costs can be saved in comparison to manufacturing from raw materials. Moreover, margins are generally higher for remanufactured products compared to new articles. Especially by implementing new management strategies based on the integration of remanufacturing systems further profits can be achieved (Butzer et al., 2013).

A successful remanufacturing strategy often implies new business models (green label, product guarantee, involvement of distribution channels, etc.), adjusted product design and performant manufacturing systems (i.e. short delivery times, effective logistic loops, building packages dealing with complexity, etc.). However, it is difficult to estimate the associated costs since these actions highly depend on the intensity and type of the manufacturing operations carried out.

From a customer point of view, the remanufactured or refurbished products are typically 60-80% of the cost of a new product mainly due to savings from material recovery and energy content of the products (ERN, 2017).

The company ACES (see related case study in operational data section) is utilizing the actual body casting in the remanufacturing process. They have reported that up to 40% cost reduction compared to a new product can be achieved by implementing remanufacturing processes. However, the cost savings highly depend on the size and value of the compressor.

Driving force for implementation

Driving forces for implementation can be of both environmental and economic nature. The main reasons that manufacturers can implement this BEMP are the less use of raw materials, higher profit margins and increased market share. Further motives include securing spare parts supply, potential for lower product prices, enabling alternative business models, reduced resource security risk and offering of product warranties.

Reference organisations

ACES, a manufacturer of compressors used for refrigeration and air conditioning.

Robotif GmbH, a company that remanufacturers robots

SFK Group, a company remanufacturing industrial bearings

The European Remanufacturing Network, provides additional information on remanufacturing for different industries, including examples from the fabrication of metal products: https://www.remanufacturing.eu/.

VDI has produced a number of informative reports and guidelines for remanufacturing, https://www.resource-germany.com/

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2.7 Link to the Reference Documents on Best Available Techniques relevant for fabricated metal products manufacturing companies

SUMMARY OVERVIEW					
It is BEMP for fabricated metal products manufacturing companies to consult the relevant Best Available Techniques (BAT) described in the relevant Reference Documents on BAT (BREFs) to identify relevant environmental issues to address and, where appropriate, implement the techniques.					
Relevant stages					
Cross cutting		Optimisation of utilities		Manufacturing	
Main environmental benefits					
Resource efficiency	**Water**	**Waste**	**Emissions to air**	**Energy and climate change**	Biodiversity
Environmental performance indicators					
- Consideration of relevant BATs (Y/N)					
Applicability	Best Available Techniques (BAT) described in the relevant Reference Documents on BAT (BREFs) applies to large companies under the scope of Industrial Emissions Directive (IED). This BEMP is very relevant for the SMEs (below the IED threshold). However, the lack of technical knowledge or capacity (of SMEs) may constitute a limiting factor.				
Benchmarks of excellence	N/A				
Related BEMPs	2.3, 2.4, 3.1, 3.2, 3.3, 3.4, 4.1, 4.2, 4.9				

Description

It is BEMP for all companies in the fabricated metal products manufacturing sector, regardless the size, to consult the relevant best available techniques (BAT) and also consider the relevant emerging techniques presented in the Reference Documents on BAT (BREFs) developed in the framework of Article 13(1) of the Industrial Emissions Directive (IED) (Directive 2010/75/EU) that are listed below.

The link to the BREFs is to be understood as an open and dynamic link. This means that companies are invited to consult always the latest adopted version of each of the BREFs (EU 2019 http://eippcb.jrc.ec.europa.eu/reference/).

The specific listed BREFs in this BEMP enable companies from the sector to find relevant BATs and technical information, suitable for the optimisation of the environmental performance of their operations and processes.

Although most BREFs give information on the BAT and emerging techniques within a specific industrial sector, several BREFs are relevant for the fabricated metal products manufacturers.

The most relevant "sector specific" (also known as "vertical" and developed for a single specific industrial sector) BREFs for companies in the fabricated metal products manufacturing sector are[28]:

- Smitheries and Foundry industry (SF)
- Ferrous Metals Processing Industry (FMP)
- Non-ferrous Metals Industry (NFM)
- Surface Treatment of Metals and Plastics (STM)
- Surface Treatment using Organic Solvents (including Wood and Wood Products Preservation with Chemicals) (STS).

The "vertical" BREFs STM and STS are the most directly linked to the fabricated metal products manufacturing sector.

There are also "horizontal" BREFs, which are relevant for several sectors and plant types. The most relevant "horizontal" BREFs for the fabricated metal products manufacturing sector are:

- Emission from Storage (EfS)
- Energy Efficiency (ENE) and
- Industrial Cooling Systems (ICS).

Table 2.7 includes examples of relevant chapters and BATs from selected BREF documents. The list does not aim at being comprehensive but shall rather give an overview of broadly applicable BAT and provide insights into where companies of the fabricated metal products manufacturing sector can find further relevant information and best available techniques.

BAT is a dynamic concept and thus the review of BREFs is a continuing process. For example, new measures and techniques may emerge, science and technologies are continuously developing and new or emerging processes are being successfully introduced into the industries. In order to reflect such changes and their consequences for BAT, BREFs are periodically reviewed and updated. The following table provides reference to the publicly available documents at the present (status November 2019). Section numbers might change in the updated versions of BREFs.

Table 2.7. Examples of BATs relevant for the fabricated metal sector and links to relevant BREF sections (status November 2019); the list of the examples of BATs is not exhaustive

Examples of BATs for different categories	Description	Relevant BATs in BREF documents (current versions)
BATs to reduce VOC emissions	Generic techniques to reduce VOC emissions from storage, handling, application of solvents and solvent-based materials e.g. paints, coatings in surface treatment activities	EfS BREF (2006), Section 5.1BREF (2006), Section 5.1 STS BREF (2019[29]), Section 18.1.1.9.2, BAT 11
BATs for waste water generated and waste water treatment	BAT to reduce water consumption and waste water generation from aqueous processes	STS BREF (2019), Section 18.1.1.13, BAT 20

[28] The full list of the existing developed BREFs is here: http://eippcb.jrc.ec.europa.eu/reference/

[29] Final draft of the revised STS BREF (2019) available online at: https://eippcb.jrc.ec.europa.eu/reference/BREF/STS/STS_FD_online.pdf

	BATs to reduce emissions to water and/or to facilitate water reuse and recycling from aqueous processes	STS BREF (2019), Section 18.1.1.14, BAT 21
	BAT is to close the materials loop for hexavalent hard chromium, cadmium	STM BREF (2006) Section 5.1.6.3
	BAT is when changing types or sources of chemical solutions and prior to their use in production to test for their impact on the existing (in-house) waste water treatment system.	STM BREF (2006) Section 5.1.8.2
BATs for use of electroplating[30]	BAT is to control the metal concentration according to the electrochemistry	STM BREF (2006) Section 5.1.6.5
	BAT is to seek to phase out PFOS	STM BREF (2006) Section 5.2.5.2
BATs for use of variable speed drives	BAT is to optimise electric motors	ENE BREF (2009) Section 4.3.6, BAT 24
	BAT is to optimise pumping systems	ENE BREF (2009) Section 4.3.8, BAT 26
	BAT is to optimise heating, ventilation and air conditioning systems	ENE BREF (2009) Section 4.3.9, BAT 27

Appropriate environmental indicators

The appropriate environmental performance indicators are:

- Consideration of relevant BATs (Y/N).

References

EU (2019): European Integrated Pollution Prevention and Control Bureau, available online at: http://eippcb.jrc.ec.europa.eu/reference/

[30] Also known as electrophoretic dipping, e-coat, ELPO, cataphoretic dipping, etc.

3 Optimisation of utilities

The selected BEMPs of this chapter focus on the supporting processes that are broadly applicable to all types of companies in the fabricated metal products manufacturing sector. This chapter gathers techniques that help companies to improve the environmental performance of supplementary processes and activities (not focussed on the core manufacturing activities) such as rational and efficient use of compressed air systems, efficient ventilation, optimal lighting etc.

The BEMPs of this chapter are listed in Table 3.1 against the direct environmental aspects and pressures, and the relevant BRef documents.

Table 3.1. Most relevant direct environmental aspects for the fabricated metal products manufacturing companies how these are addressed in the optimisation of utilities chapter

BEMPs	Most relevant direct environmental aspects	Related main environmental pressures	Relevant BREFs
3.1 Efficient ventilation 3.2 Optimal lighting 3.3 Environmental optimisation of cooling systems 3.4 Rational and efficient use of compressed air systems 3.5 Use of renewable energy 3.6 Rainwater collection	Industrial processes and operations	Energy Water Emissions to air Waste: hazardous	ENE STS ICS

3.1 Efficient ventilation

SUMMARY OVERVIEW

BEMP is to improve the efficiency of the ventilation system and reduce its energy use by:

- performing a study of the manufacturing site, including buildings and processes;
- mapping the sources of heat, humidity, and pollutants to indoor air;
- reducing these sources by e.g. implementing effective maintenance that limits emissions of pollutants or isolating a source thanks to an air pressure differential;
- defining the actual (current and future) needs for ventilation;
- carrying out an audit of the existing ventilation system, to compare the defined needs with the current installation;
- re-designing the ventilation system to reduce its energy use and the volume of air supplied (which reduces the energy use for heating or cooling it). Demand based ventilation can be designed to avoid peak draws and allow more energy efficient operation with down-sized equipment.

A similar approach can be also implemented for new installations, whereby the needs are defined on the designed building and processes and there is further opportunity to minimise them by influencing their design.

Relevant stages

Manufacturing	**Supply chain**	End-of-life

Main environmental benefits

Resource efficiency	Water	Waste	Emissions to air	**Energy and climate change**	Biodiversity	Hazardous substances

Environmental performance indicators

- - Effective air volume extracted from the building (m^3/hour, m^3/shift or m^3/production batch)
- - Demand driven ventilation system (Y/N)
- - Energy use for ventilation per m^3 building (kWh/m^3 building)
- - Energy use to heat or to cool the air used for ventilation per m^3 building (kWh/m^3building)

Applicability	The BEMP is applicable to all types of companies in this sector, including SMEs. Insufficient in-house technical knowledge can also sometimes constitute a barrier to implement all the elements of this BEMP. The safety of the staff of the manufacturing facility must be set against the energy efficiency of the ventilation system in place.
Benchmarks of excellence	Demand driven ventilation is implemented to reduce HVAC energy use
Related BEMPs	2.1, 2.3, 2.7

Description

Ventilation is the process by which fresh air is circulated within a building. When dust, fumes or mist is emitted from processes, such as evaporating lubricoolants from machining, smoke from thermal processes like welding and forging, and vapours from painting booths, more intense ventilation is needed to ensure an appropriate level of air quality in the building for the employees working on-site and for the manufacturing processes taking place.

This BEMP covers a range of measures to improve the efficiency and reduce the energy use of the ventilation system. Please note that specific opportunities to optimise ventilation for painting processes such as paint booths are addressed specifically in Use of predictive control for paint booth HVAC management BEMP.

In a fabricated metal product manufacturing company, the removal of emissions, dust, fumes or mist from the indoor environment is mainly ensured by isolating the space where a machine/process that generates emissions is located and extracting the air from that space or by installing a local exhaust which captures the contaminants at or near their source. For instance, in the case of welding, the first is mainly applied in case of automatic or robotic welding and the second in case of manual welding.

However, no local exhaust system is 100% effective in capturing fumes and the capture efficiency has a greater influence on the indoor air quality than the filtration efficiency. No filter device is effective until the fume is drawn into it. On welding, there will be circumstances, because of the size or mobility of the welding zone where installation of local exhaust system right in the welding zone may not be possible. Also, local exhausts are typically not efficient in removing fumes generated after welding at the heat-affected zone.

General ventilation is needed to dilute pollutants not captured by the local exhaust systems, in complement to a general exhaust system that is used to evacuate air from the building. General ventilation systems supply make-up air to replace air extracted by the local and general exhaust systems. The supply air is also used to heat and cool the building.

In order to prevent outdoor air infiltration creating cold drafts in winter, and hot humid air to enter in summer, buildings need to be pressurised. Therefore the volume of outside air supplied by a general ventilation system exceeds the volume of air exhausted.

Special attention is given to ventilation of areas with grinding and polishing operations, especially in the case of products with aluminium. Air supply and exhaust should be arranged in such a way as to create low velocity-low turbulent airflow preventing dust dispersion in the shop. Low airflow, high vacuum exhaust systems built in grinding and polishing machines significantly reduce contaminant load on the building (Zhivov A.M. et al., 2000).

In fabricated metal products manufacturing companies there is often scope to reduce the energy use of the ventilation system by[31]:

1. Understanding the building and its air flows;
2. Mapping the sources of heat, humidity and pollutants (dust, fumes, etc.) in the building;
3. Reducing the emissions where possible;
4. Defining the actual (and future) needs for ventilation;
5. Carrying out an audit, to compare the defined needs with the current installation;
6. (Re)design the ventilation system.

These steps are described in the following paragraphs.

[31] Ventilation must been seen as a part of the global HVAC (Heating, Ventilation and Air Conditioning) of the building.

Understanding the building and its air flows

The installation of a ventilation system requires a profound study of the features of the manufacturing site, the buildings and the processes installed. Elements such as design, physical layout, mechanical systems, equipment and installed manufacturing processes and space usage are all essential as they can affect air quality. Furthermore, the air distribution system requires particular attention: how outdoor air gets in, how it circulates throughout the building, etc. (TSI, 2013).

Mapping the sources of heat, humidity and pollutants in the building

The next step is to carry out an inventory of all sources of heat, humidity and pollutants used on site. Different heating processes like forging, hot forming, welding, heat treatment, surface treatments at elevated temperatures, etc. are applied by companies in the fabricated metal products manufacturing sector. Open water systems, which can cause humidity problems, are limited, but a lot of processes (e.g. post metallurgical treatment processes) can emit chemical products, which enter the air as aerosols or vapour.

Reducing the emissions where possible

In order to reduce the need for ventilation, for each source, all the possible means to reduce the emissions in the first place need to be considered, including:

- Removing the source;
- Repairing the source so it no longer contributes with pollutants;
- Isolating the source with a physical barrier;
- Isolating the source using air pressure differential;
- Minimising the time people/staff are exposed;
- In case of heat, is it an option to put a heat exchanger and reuse the heat;
- In case of heat vapour/steam, it is an option to condense them and reuse the latent heat and product.

Defining the actual (and future) needs for ventilation

After the reduction of the ventilation requirements, by reducing the sources of pollution, the ventilation needs can be defined more precisely, also taking into account applicable legislations and standards [32].

Carrying out an audit, to compare the defined needs with the current installation

After the precise definition of the ventilation needs, auditing can start. Besides reviewing the ventilation equipment in place and its functioning, it may be helpful to check its energy use as well as carrying out measurements of the air quality.

Re-designing the ventilation system

The last step is to design, or re-design, the ventilation system optimising energy efficiency of equipment, layout of the installation, heat recovery and air flow management. To reduce the energy use, the following techniques can be considered:

- Using variable speed drive motors for ventilation;
- Optimising position and orientation of blowers;
- Controlling the air volume in function of the ventilation needs;
- Recovering heat from the exhaust air;
- Converting the extraction systems serving multiple workstations into on-demand systems;
- More broadly, implementing demand management based ventilation.

The idea of demand management based ventilation is matching as closely as possible the level of ventilation provided to the actual needs at any given time. Ventilation can be

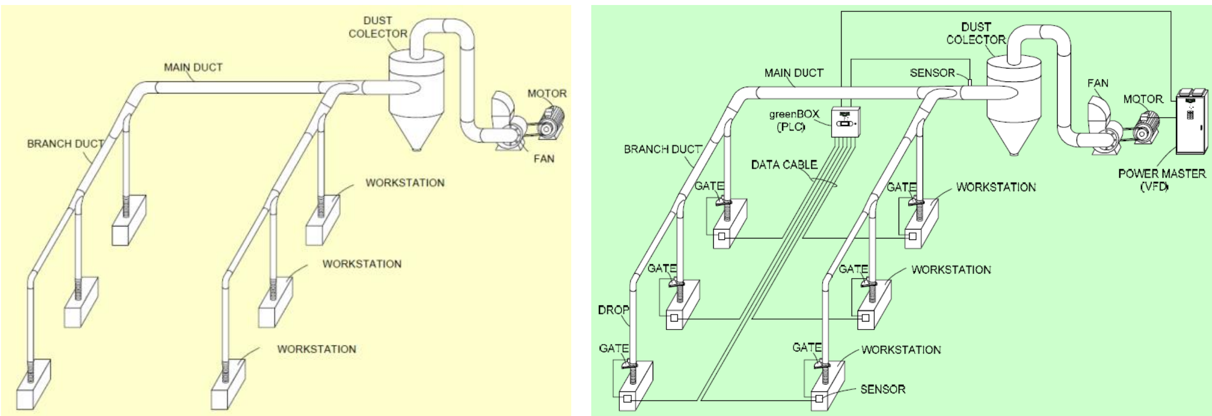
[32] For instance, the EU directive (2010/31/EU) on the energy performance of buildings and the WHO guidelines on indoor air quality (2010) have to be taken into account when the ventilation needs are defined.

regulated by monitored demand, configuring the machine shop operations such to avoid peak draws and allow more energy efficient operation with down-sized equipment.

Concerning the recovery of heat, it is important to use heat exchangers that avoid cross-contaminations, such as run-around coils, and are able to support the range of temperatures of the exhaust air.

As per the conversion into on-demand systems, these are relevant for ventilation systems that are designed to enable ventilation from multiple (similar) workstations all connected to one dust collector, filter and fan. In conventional systems, the size of the fan motor is chosen based on the theoretical maximal ventilation need. However, data from real factories show that, typically, less than 50% of machinery is working at any given time; therefore, 50% of machinery is not producing dust (fume, mist); despite this fact, suction continues from all machines at full speed (Litomisky, 2006). In the on-demand systems, each workstation is equipped with a sensor that detects when ventilation is necessary, and use a motorized gate to close the ventilation duct when ventilation is not necessary (Figure 3.1). The speed of the fan is adjusted to achieve a proper air volume in the ducts, achieving average electricity savings of 68% over unregulated, classical systems. If dust or other materials are to be transported through the ducts, then it is necessary to maintain a set minimum velocity in the ducts to prevent the material from settling; also, minimum negative pressure should be maintained to overcome pressure losses in the ducts. When gates at non-working workstations are closed, air volume and subsequently air velocity in the main duct will drop and dust can settle. An on-demand dust collecting system solves this problem by using a PLC (industrial computer) that calculates the necessary air volume and the necessary negative pressure based on information from the sensors. The PLC adjusts the speed of the fan accordingly, and it also opens additional gates at non-working machinery if this is necessary for maintaining proper air velocity.

Figure 3.1. Left: Unregulated system with duct system directly connected to dust collector, fan-motor combination. Right: On demand system with sensors to close duct gates. VFD controlled fan motor controlled by PLC (Litomisky, 2006)



Achieved environmental benefits

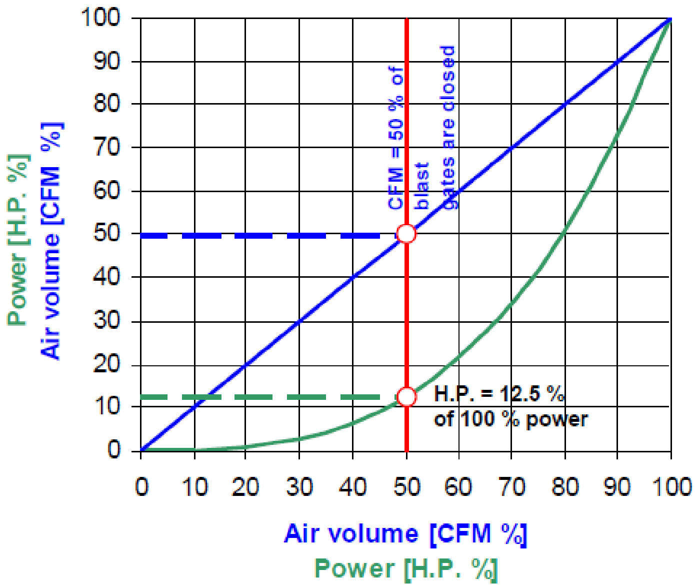
The major environmental benefit of implementing the measures described in this BEMP is the reduction of energy use. This leads to an overall reduction of the greenhouse gases (GHG) emissions caused by the generation of electricity[33].

[33] If the electricity is bought from the grid, the actual level of indirect emissions reduction will depend on the energy mix of the electricity supplier. See BEMP 3.5 on the use of renewable energy for further information.

By optimising ventilation, companies can reduce their direct energy use for ventilation by 20 to 70% (Schlosser, 2011). This is because the implementation of demand management processes provides better insights in real ventilation needs resulting in down sized installations as not all workstations or processes operate at 100% during the total shift time. Moreover, a reduction in air flow results in a more considerable reduction in energy use (Figure 3.2): a 20% reduction in the air flow can reduce by 50% the energy use of the fan (European Commission, 2009).

Very importantly, beyond the energy use for ventilation, reducing the airflow allows reducing substantially the energy use for heating during winter and cooling during summer (Siemens, 2010).

Figure 3.2. Fan Law: at 50% reduction of air-flow (which is achieved by automatically closing gates on non-operating machinery), fan motor will consume only 12.5% of electricity of what is required when suction is running at all workstations. This is a reduction of 87.5% (Litomisky, 2006)



Lowering of ventilation also leads to noise reduction due to lower fan speeds and lower extraction volumes.

Duct diameters are smaller when demand controlled ventilation is applied because they are optimized for example for 70% of air volume. This can be considered an additional environmental benefit in terms of resource efficiency (reduced material consumption for their manufacturing).

Appropriate environmental performance indicators

The following environmental performance indicators can be used by fabricated metal products manufacturing companies to track progress in the area of efficient ventilation:

- Effective air volume extracted from the building (m^3/hour, m^3/shift or m^3/production batch) or air volume extracted per m^2 of building surface (m^3/hour/m^2, m^3/shift/m^2 or m^3/production batch/m^2)

- Demand driven ventilation system (Y/N)

- Energy use for ventilation per m^3 building (kWh/m^3 building)

- Energy use to heat or to cool the air used for ventilation per m^3 building (kWh/m^3)

The different indicators listed above can be compared before and after implementation of the measures described in this BEMP for an understanding of their effect.

Cross-media effects

When implemented correctly, the measures for improving the efficiency of the ventilation system in fabricated metal products manufacturing plants and reducing their energy use described in this BEMP do not lead to negative effects on other environmental pressures.

Operational data

Case Study – Aerospace Component Manufacturing Plant – demand control ventilation combined with other energy efficiency improvements

Aerospace component manufacturing is a manufacturer of metallic components for jet engines. In a manufacturing plant based in the US, they performed an analysis of their processes with the view to upgrade the on-site ventilation system (Rappa, 2012):

- Manufacturing make-up air and exhausts analysed;
- 150,000 – 250,000 cubic foot/minute (cfm) of makeup air supplied and exhausted annually;
- 1,700,000 kWh, 32,000 mmBTus (million British Thermal Units), $435,000 annually;
- 4-7 air changes per hour.

They then decided to proceed with the following energy efficiency improvements:

- exhaust heat recovery;
- demand control ventilation;
- variable speed drives;

The achieved results were savings of approximately 1,100,000 kWh.

Case Study – Daimler Truck

By implementing the measures described in this BEMP, at Daimler Truck the plant ventilation was reduced from >30 Nm³/h/m² to 17 Nm³/h/m², as the machine ventilation was reduced from 1,800 Nm³/h/m² to 720 Nm³/h/m². A saving of 50% was measured (Schlosser, 2011).

Applicability

The measures of this BEMP are broadly applicable to all type of fabricated metal products manufacturing plants, including SMEs. It is more suitable for plants that apply forging, welding, paint spray and machining processes and specifically for new built-facilities or renovated production lines.

The installation of an on-demand ventilation system is more complex than a conventional ventilation unit. Insufficient in-house technical knowledge can also constitute a barrier to (properly) implement the measures of the BEMP. Demand data capture and controls on plant level demand requires site-wide coordination. The above elements can constitute a constraint for the implementation of the measures of this BEMP in SMEs.

The on-demand ventilation systems must ensure at the same time the safety and comfort of the workers and staff by supplying the required amount of air. This may be set against the overall energy efficiency of the ventilation system.

As regards heat recovery systems, their viability increases when (Sustainable Energy Authority of Ireland):

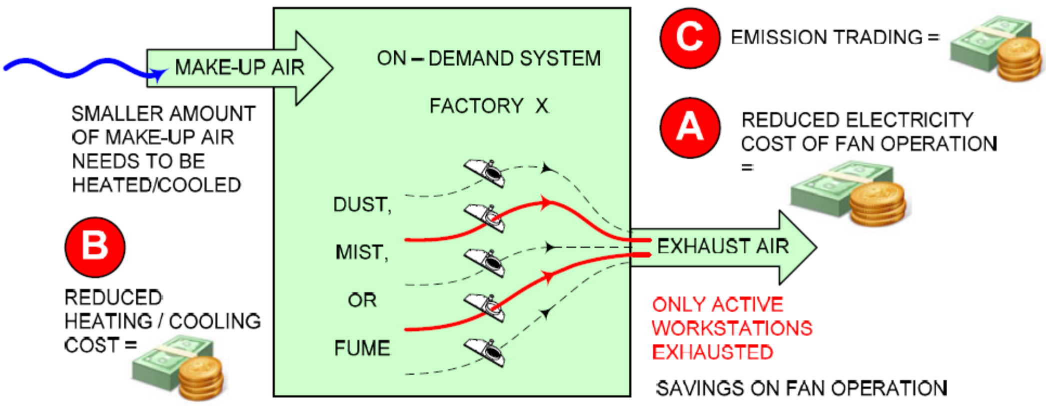
1. The number of air changes per hour is high and the heating season (or cooling season) is long;
2. The temperature difference between the supply and extract air streams is significant;
3. The supply and extract air streams are within close proximity;
4. The ventilation system operates for extended periods of time.

Economics

Generally, the investment and maintenance costs of an on demand ventilation system are higher compared to a conventional ventilation one. This is because the on demand ventilation systems need steering, sensors, etc., which are typically worthwhile actions in most cases thanks to the achievable savings. Similarly, the payback time may be longer but not significantly (this is subject to the system's capacity and the type of manufacturing processes carried out) compared to the conventional ventilation systems.

Economic savings occur through the reduction of costs from energy use (Figure 3.3). For on-demand ventilation systems, they may range between 20 to 80% compared to on-off non-demand-controlled (conventional) ventilation (Litomisky, 2006; Siemens, 2010 and Schlosser, 2011). Savings through lower need of heating or air conditioning are typically two times higher than the fan electricity savings; though this strongly depends on geographical location, operating hours and energy costs of the manufacturing site (Litomisky, 2006). The total ventilation costs vary substantially between different companies. In fact, costs depend on heated air, the airflow or the filtering needs within the manufacturing site and the air quality requirements, which at the same time depend on the process carried out and the human exposure to the dust and other pollutants and particles produced. Additionally, the costs for filters and their maintenance need to be considered in details by the manufacturers.

Figure 3.3. Savings by on-demand ventilations (Litomisky, 2006)



Note: A. Fan operation electricity savings, B. air conditioning/heating savings (if used), and C. emission trading (where available).

As per heat recovery, Table 3.2 summarises the effects on the capital and operating costs associated with the installation of such system. Typical payback periods (Table 3.2) for different heat recovery devices range between 0.7 and 1.3 years but can go up to 6 years while still be reasonable (Sustainable Energy Authority of Ireland).

Table 3.2. Potential effects on capital and operating costs associated with the installation of a heat recovery system (Sustainable Energy Authority of Ireland).

	Expenditure	Savings
Capital costs	-Design Costs -Supply and installation costs of the complementary assembly -Modifications to existing plant and services to accommodate the new equipment -Additional plantroom space -Controls	-Reduction in central plant size -Reduction in distribution pipework
Running Costs	-Additional operating costs due to increased fan power -Pump operating costs where run-around coils are employed -Increased maintenance	-Nett reduction in operating costs due to heat recovery -Reduced carbon emissions

In the Aerospace Component case (see operational data section for further information), annual economic savings of $230,000 were achieved. This resulted in a payback time of the investment made of less than 2 years (Rappa, 2012).

Driving force for implementation

The main driving forces for implementation are:

- Reduction of energy use and carbon footprint;
- Cost savings;
- Improvement of Indoor Air Quality (IAQ) and employee well-being.

This last element is particularly relevant beyond energy and cost savings: auditing and redesigning/improving the ventilation system allows improving the well-being of all workers and specifically those involved in manual processes where fine particles, fumes or dusts are emitted. Given the potential adverse health effects of exposure to these, a more effective system means reduced health risks for employees and a more pleasant working environment.

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3.2 Optimal lighting

<table>
<tr><td colspan="7">SUMMARY OVERVIEW
In order to achieve optimal lighting in new built and existing manufacturing sites, a lighting study, to define the actual (current and future) light needs and a lighting plan, to define the optimal lighting solution (light systems, fittings, lamps, use of daylight, etc.) need to be carried out.
It is BEMP for manufacturers of fabricated metal products to optimise existing and new lighting systems by:
• maximising the use of daylight;
• installing presence detectors controlled lighting in key locations;
• monitoring separately the energy use for lighting;
• selecting the most appropriate energy efficient lamps in terms of their planned hours of use and area of installation;
• implementing a regular plan for cleaning and maintenance for the lighting system.</td></tr>
<tr><td colspan="7">Relevant stages</td></tr>
<tr><td colspan="2">Cross cutting</td><td colspan="3">Optimisation of utilities</td><td colspan="2">Manufacturing</td></tr>
<tr><td colspan="7">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td><td>Hazardous substances</td></tr>
<tr><td colspan="7">Environmental performance indicators</td></tr>
<tr><td colspan="7">- Use of daylight wherever possible (Y/N)
- Share of the lighting controlled by sensors (motion sensors, daylight sensors) (%)
- Energy use of lighting equipment (kWh/year/m² of lighted floor)
- Installed lighting power (kW/m² of lighted floor)
- Share of LED/low-energy light bulbs (%)
- Average efficacy of luminaires throughout plant (lm/W)</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="5">This BEMP is broadly applicable to all types of companies in the sector, including SMEs. However, it is more suitable for new built manufacturing sites or renovated production lines.
The natural lighting is an important element on efficient lighting systems, but its implementation may be limited to all locations due to local natural conditions. Similarly, its applicability may be limited to existing manufacturing sites due to architectural constraints.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="5">N/A</td></tr>
<tr><td colspan="2">Related BEMPs</td><td colspan="5">2.1, 2.3, 2.7</td></tr>
</table>

Description

Metal products fabrication requires optimal lighting for safety reasons and for product quality check. The energy use for the lighting system of a production hall contributes significantly to the overall energy use of a company (the significance of the contribution depends on the energy intensity of the other energy using activities carried out in the company). Energy needs for lighting are higher in case of e.g. long operating hours (two or three shifts) and/or work floor, and when using older lighting technology (e.g. high pressure sodium lamps). In some fabricated metal products manufacturing companies lighting is responsible for 10% of the total energy use of the plant (Dialight, 2015).

High-quality lighting allows workers to see workpieces, tools and measuring instruments precisely and eases spatial perception. This BEMP aims at supporting fabricated metal products manufacturing companies to identify environmental improvement possibilities for their lighting system, while eliminating unsatisfactory lighting conditions in their industrial sites.

In general the following factors have a positive impact on the reduction of energy use for lighting (Zumtobel Lighting GmbH, 2008):

- Sensible control of lighting
- Use of daylight
- Use of presence detectors
- Intelligent consideration of hours of use
- Energy-efficient lamps
- Need-based use of luminaires and lighting solutions, specified for the respective application
- Constant lighting control (maintenance control).

Optimisation of existing lighting systems can be an opportunity to reduce costs and the carbon footprint of the company. To implement energy reducing lighting methods, companies can take the following three steps:

1. Perform a lighting study, to define the actual (and future) needs of light;
2. Perform an audit, to compare the defined needs with the current installation;
3. Perform a lighting plan, to define what the optimal solution (light system, fitting, lamps, natural light, etc.) is in order to fulfil the needs.

In case of new installations, only step 1 and 3 are needed.

A *lighting study* (step 1) defines the light needs for each activity. Depending on the type of activity (precision work or rough work) more or less light is needed. The lighting study takes into account the different amount of daylight for each room/hall during day/night, week/weekend, summer/winter and the different needs during each period. The lighting study also gives an overview of the light duration for each location (e.g. minutes for corridors, only when people pass, or the whole day for workspaces).

An energy audit (step 2) is an inspection, survey and analysis of energy use in a manufacturing site in order to reduce the amount of energy input into the system without negatively affecting the output (see also BEMP 2.3 on energy management for more details on this subject). In the case of lighting, the energy audit would include the identification of systems, the evaluation of working conditions, the analysis of the potential impact of improvements and the preparation of the energy audit report regarding lighting systems (Adesh Institute of Engineering & Technology, 2012). In order for an energy audit to be as much reliable as possible, regular energy monitoring of lighting is key, in order to provide reliable figures to the analysis of the audit.

A *lighting plan* (step 3) gives the optimal solution (e.g. amount of luminaires and luminous intensity) for each area/room/hall of the company. Daylight must be chosen as a first option. Lighting plans aim to indicate the right solution for each component of the light systems. In case of new built buildings, lighting studies and lighting plans must be part of the design. Activities and the placement of windows and dome skylights must be planned in function of the orientation of the sun.

During step 3, the different components of the light system are defined. Manufacturers need to take into account:

- the surroundings (building, room, workplace, street, parking place, etc.);
- the choice of suspension of the luminaires (ceiling, wall, pole, etc.);
- the lighting calculation in accordance with the appropriate standard, including the optimization to the lowest energy consumption;
- the choice of a lighting management system including sensors, controls and communication network;
- the choice of light sources and luminaires including ballast and optic; in this regard natural light should be exploited as much as possible, since it can substantially contribute to lowering energy consumption but also improving the work environment. Design with natural light is a critical step, since currently most of the metal manufacturing installations are not designed taking advantage of the natural lighting;
- the choice of an emergency escape lighting system;
- the installation and commissioning of the whole system;
- lighting control system; in a lighting control system, light and energy control is integrated at building level; for instance a system can simultaneously apply five different energy management strategies in order to save as much power in a building as possible, comprising:
    - intelligent time control;
    - daylight dependent system;
    - movement detection;
    - individual control;
    - limitation of the peak output.

To design lighting systems/lighting plans, there are different design and calculation software available.

Achieved environmental benefits

New light systems result in a significant reduction of the electricity consumption. This leads to an overall reduction of the indirect greenhouse gasses (CO_2) emissions.

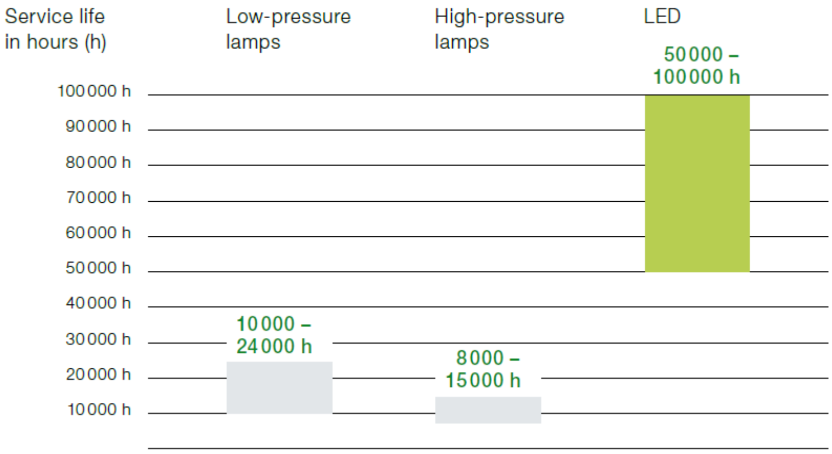
Based on the first results of EU Ecodesign Preparatory Study on Lighting Systems (Vantichelen et al., 2015) the industry[34] can save up to 70% on indoor lighting and up to 90% on outdoor lighting when implementing an optimized lighting system. The whole European industry (EU-28) consumes 18 TWh for indoor and 6 TWh for outdoor lighting per year. There are no detailed numbers available for the Fabricated Metal Products sector. Other sources (i.e. Encon, 2015) give savings potentials for electricity of 50% to 80% based on case studies in different industrial sectors.

Additionally, new light systems using up to date luminaires can lead to significant environmental improvements. In the case of LED luminaires, regularly replacing the light sources is not necessary, even after 50,000 hours of operation the LED mostly still

[34] This study will provide the European Commission with a technical, environmental and economic analysis of lighting systems as required under Article 15 of the Ecodesign Directive 2009/125/EC.

achieve a luminous flux of at least 70% of the initial level. On the other hand, a HIT lamp will fall below 60% of its initial level already after a few months. Accordingly, the light source must be replaced more frequently, leading to higher waste amounts generated in comparison to LED (Zumtobel Lighting GmbH, 2015). The environmental benefit of LED is illustrated in Figure 3.4, which gives a comparison of the service life in hours of three different lamps available on the market (low-pressure lamps, high-pressure lamps and LED).

Figure 3.4. Comparison of service life in hours of low-pressure lamps, high-pressure lamps and LED (Zumtobel Lighting GmbH, 2007)



Appropriate environmental performance indicators

The appropriate environmental performance indicators for this BEMP are listed below:

- Use of daylight wherever possible (Y/N)
- Share of the lighting controlled by sensors (motion sensors, daylight sensors) (%)
- Energy use of lighting equipment (kWh/year/m² of lighted floor)
- Installed lighting power (kW/m² of lighted floor)
- Share of LED/low-energy light bulbs (%)
- Average efficacy of luminaires throughout plant (lm/W)

Cross-media effects

Based on measurements (Technische Uni, 2015), 98% of the lighting in workspaces in the European Union is insufficient in regard to EU standards. When the original lighting installation is not in line with the regulatory standards on lighting of work places, more light is needed, leading to a possible increased energy use. If relighting does not lead to a reduced energy use, this is due to the fact that the old installed lighting system was insufficient for the employee welfare. The overall result of optimising lighting can be a better lighted company, without direct energy savings.

Operational data

Case Study: Black&Decker

The total electricity consumption decreased for about 66% in a warehouse of Black&Decker, as lighting was the main electricity consumer. The main steps were: performance of a lighting study and audit, replacement of light armatures, placement of movement sensors (react when fork-lift truck arrives), and placement of dimmable ballasts to reduce the light intensity to 3% of the maximum capacity. The study results in more light where it is needed by employees. The whole project was awarded the EU GreenLight certificate (Encon, 2015).

Case study: ALANOD Aluminium-Veredlung, aluminium finishing industry, Germany

At ALANOD Aluminium-Veredlung a new lighting system in the warehouse and assembly facility lead to a reduction of 67% of the electricity consumption of lighting. The payback period was 1.1 years (ETAP, 2011). In other companies, new light systems lead to comparable reductions (e.g. 50% at John Deere, 60% at Verhoef). The savings were reached by a combination using other lamps, reflectors and using a management system to turn on/off lights.

Case Study: Martisa manufacturing, producer of metal pieces, Spain

Martisa manufacturing had 32,400 W high pressure sodium (HPS) lights installed in their 1,288 m^2 manufacturing plant in Spain, resulting in a high energy use. The facility was subject to frequent dimming and flickering problems, leading to the instalment of a more robust lighting solution. The performance instability of the HPS was also generating irregular colour rendition areas varying between 118 and 270 lux at floor level, causing an insufficient working environment for employees. Further problems arose when the lights took ten minutes to re-strike following power outages. Maintenance was also an issue, as the HPS lights were mounted at a height of 9 metres, ran ten hours a day, five days a week and had to be replaced every 10,000 hours, each at a unit replacement cost of 50€ plus the use of a mobile elevation platform that cost 100€ per day. Relighting was implemented with 150W DuroSite LED High Bays.

After optimizing their lighting, the company is benefiting of 69% reduction in lighting energy consumption and reduced carbon emissions from solid-state LED technology. The implemented LED technology suffers no flickering or dimming effect. The lux level is now steady at 200 at floor level, giving improved and consistent colour rendition, while the LEDs' instant-on ability means that there is no re-strike delay following power outages. Furthermore the LED technology installed carrieda 5-year continuous performance warranty and has an expected lifetime of 60,000 hours. This has also greatly reduced the maintenance burden and cost for the company (Dialight, 2015).

Case Study: Olympus KeyMed - producer of metal medical equipment, United Kingdom

The company Olympus KeyMed's is manufacturing with sheet metal as well as paint shop. In the 3,380 m^2 facility over 100 metal halide high bay lights were installed previously. Measurements showed that the 400 W high bays were actually operating at 440 W and accounting for 10% of the total energy usage.

Olympus KeyMed also found that the metal halide high bays were lasting two years at best or 15,000 hours on average, though replacement cycles could be shorter as a result of heat generated and accumulation of dirt.

After researching the LED market and with the recommendation of energy consultants a lighting plan was made. The metal halide high bay lights were replaced with 150 W LED armatures. This led to the discovery that the actual consumption of the LED lights including drivers was 5-10% lower than the expected 150 W – an additional energy saving bonus while maintaining the same light level but immediately reducing energy usage by over 68%. As a result, Olympus is now on target to cut carbon emissions by 85 tonnes per year.

On the manufacturing side of the business the lighting runs 24 hours/5.5 days a week, while in logistics it runs 14 hours/5 days a week and Olympus KeyMed is introducing sensor control in both units to deliver further energy and carbon reductions. The control software has a payback period of less than 4 years (Dialight, 2015).

Case study: ArcelorMittal– steelworks manufacturer, Poland

ArcelorMittal, based on Poland, illuminated the workplace for cranes that carry the semi-finished products for further processing. Optimal lighting solutions were provided by the company Solatube and the objective was to illuminate two separate halls by installing the systems from the top of the roof without disrupting the manufacturing operations. On technical grounds, the objective of luminating the first hall was to achieve the average luminance of 100 lux (dimensions of the hall 36 m width, 160m length and 22 m height) while for the second hall (dimensions 30 m width, 72 m length and 22 m height) the objective was to achieve the average luminance of 200 lux. Aditionally, they wanted to use daylight as much as possible and thus a special system to bring in the two halls daylight was installed (Maciag, 2014).

Case study: Volvo Cars - manufacturer of cars and trucks, Belgium

In Volvo manufacturing plant in Ghent, they renovated the lighting system. The lighting has been divided up into a large number of small zones, each of which can be independently switched on and off. General lighting and process lighting turns off automatically in each zone depending on the amount of light coming in through the new skylights. All manual switches in the plant are being removed. Switching times per zone have been adapted. In irregular situations, such as night working, weekends or layoff, lighting can be controlled manually for each zone from a central location (Volvo, 2012).

Applicability

Optimal lighting is broadly applicable in all types of companies, including SMEs. Use of natural lighting might not be possible at all facilities because of limited natural light available due to natural conditions. In new facilities or in major renovated production lines, substantial improvements of lighting systems are easier to implement and the economic feasibility is much higher.

Economics

Economics highly depend on the size of the (re)lighting project. The GreenLight programme[35] (EU, 2015) provides calculation spreadsheets[36] for assessing the cost-effectiveness of one (or two) energy-efficient lighting system(s) compared to one conventional new installation. Other companies provide comparable spreadsheets (Energie+, 2015). The payback time varies between 1 and 4 year, taking into account all costs: study work, new lamps, ballasts, etc. and installation costs (Encon, 2015).

Different economic models are possible to finance (re)lighting projects. Manufacturers can choose to finance their own relighting projects or they can prefer to outsource these activities.

A third option is the servitisation of light. In that case, the company pays for a light service, while the contractor provides the lighting infrastructure. The service supplier of 'light' has the incentive to reduce the lighting cost for its client (mainly through the same

[35] The GreenLight Programme is a voluntary pollution prevention initiative encouraging non-residential electricity consumers (public and private), referred to as Partners, to commit towards the European Commission to install energy-efficient lighting technologies in their facilities

[36] The spreadsheet can be downloaded from the link below: http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/files/documents/GreenLight/gl_calc3.xls

or higher light performance for a lower energy cost) on the one hand, and to design/search for lighting products with a longer lifetime, and an optimal use of daylight.

The light as a service concept allows the Fabricated Metal Products companies to reduce the risk on two levels. First, the technological risk, this risk is taken over by the light supplier who is under control of the lighting product design process. Secondly, the financial risk for the company is reduced, since no investment is needed. The light provider has incentives to improve and optimize the product design for longevity and to reduce the energy consumption by introducing calendar control, day light sensors, presence sensors etc. Even so, the supplier can capture data on the product use and provide the company user profiles. This can lead to further energy efficiency improvements.

The company Zumtobel Lighting GmbH has published operating costs of a practical example from the industry, using their "Now!" agreement *(Zumtobel Lighting GmbH, 2015).* Table 3.3 gives an overview of the old and new lighting system and respective annual operating costs and profit of the new lighting system and illustrates clearly the economic advantage over the previous lighting system.

Table 3.3. Overview of an old and a new installed lighting system in the industry with corresponding annual operating costs (Zumtobel Lighting GmbH, 2015)

Old lighting system	New lighting system
31,666 € operating costs / year	16,222 € operating costs / year
100 luminaires, HQL with conventional ballast 400 W	100 luminaires, CRAFT 280 W
480 W installed load / luminaire	280 W installed load / luminaire
48 kW installed load / total	28 kW installed load / total
	3,345 € immediate annual profit
	15,444 € future annual profit (9th year)

Driving force for implementation

Increased energy costs for companies make relighting an increasing interesting option. The possibility of saving energy and therefore energy costs is among main driving forces for implementing an optimized lighting system.

Additionally, when light quality is increased, a measured positive effect on working behaviour of employees has been detected (Schlangen et al, 2014). Furthermore, a review conducted at the Ilmenau Technical University, Germany, stated that elevating the light intensity according to regulations in working areas, increased working results up to 20-40%.

Hence, increasing working results and employee well-being are two additional important driving forces for implementing an optimized lighting system.

In the case of servitisation of lighting, companies can focus more on their core activities, reducing risks and resources dedicated to lighting optimization. These benefits, which come from an optimized lighting, are also driving forcing for an implementation.

Reference organisations

ALANOD Aluminium-Veredlung – producer of anodised and PVD coated aluminium coil

Relighting of warehouse and assembly facility leads to a reduction of 67% of the electricity use of lighting. The payback period is 1.1 year.

Martisa manufacturing (ES), producer of metal pieces (Dialight, 2015). http://www.martisa-components.com/ca/

Olympus KeyMed, UK, producer of metal medical equipment (Dialight, 2015): http://keymed.co.uk/index.cfm

John Deere – provider of agricultural technology; refurbished the lighting at its 42 hectare factory site to save energy and to improve at the same time working conditions. The workshops were fitted with reflector light carriers with TL5 lamps. A light management system with daylight-dependent control combines high efficiency with low maintenance. In some buildings the solution has achieved energy savings of up to 50% with visibly better lighting and positive employee feedback (Philips, 2011).

Verhoef – production of all types of aluminium lifeboats, aluminium (patrol-)boats as well as other aluminium products for the shipbuilding industry such as gangway systems; relighting of the production hall results in savings of 60% on electricity for light and a payback period: 1.5 year (Philips, 2015).

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3.3 Environmental optimisation of cooling systems

<table>
<tr><td colspan="6">SUMMARY OVERVIEW
BEMP is to systemically improve the energy efficiency and overall environmental performance of cooling systems for the machine shops of the manufacturing site by:
• Striving to reduce the cooling demand;
• Performing an audit of the cooling system in place in order to compare the defined needs with the current cooling installation;
• Redesigning the cooling system with a focus on maximising energy and water efficiency and minimising GHG emissions.</td></tr>
<tr><td colspan="6">Relevant stages</td></tr>
<tr><td colspan="2">Cross cutting</td><td colspan="2">Optimisation of utilities</td><td colspan="2">Manufacturing</td></tr>
<tr><td colspan="6">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td></tr>
<tr><td colspan="6">Environmental performance indicators</td></tr>
<tr><td colspan="6">- Total equivalent warming impact (TEWI) of the cooling system (CO_{2e})
- Global warming potential (GWP) of refrigerants used (CO_{2e})
- Energy use for cooling (kWh/year; kWh/kg finished product or manufactured part)
- Water use (tap water / rain water / surface water) for cooling (m^3/year; m^3/kg finished product or manufactured part)</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="4">The BEMP is applicable to all types of companies in this sector, including SMEs. The BEMP is more suitable for new built or renovated manufacturing sites.
However, the implementation of this BEMP may require support from external partners, which may constitute a possible barrier, especially for the SMEs.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="4">N/A</td></tr>
<tr><td colspan="2">Related BEMPs</td><td colspan="4">2.1, 2.3, 2.7</td></tr>
</table>

Description

Manufacturing sites require industrial cooling in order to protect certain processes and involved equipment where the use of the heating, ventilation and air conditioning (HVAC) system of the building is not sufficient. Industrial cooling systems can be categorised by their design and by the main cooling media: water, air, or a combination of both.

In this BEMP, a systematic approach to improve the environmental performance of cooling systems is described in detail for the machine shops in fabricated metal product manufacturing plants where cooling circuits are often based on water circuits. This approach typically consists of the 3 following steps:

i. define needs and reduce demand

ii. audit current cooling system and

iii. (re)design cooling installation.

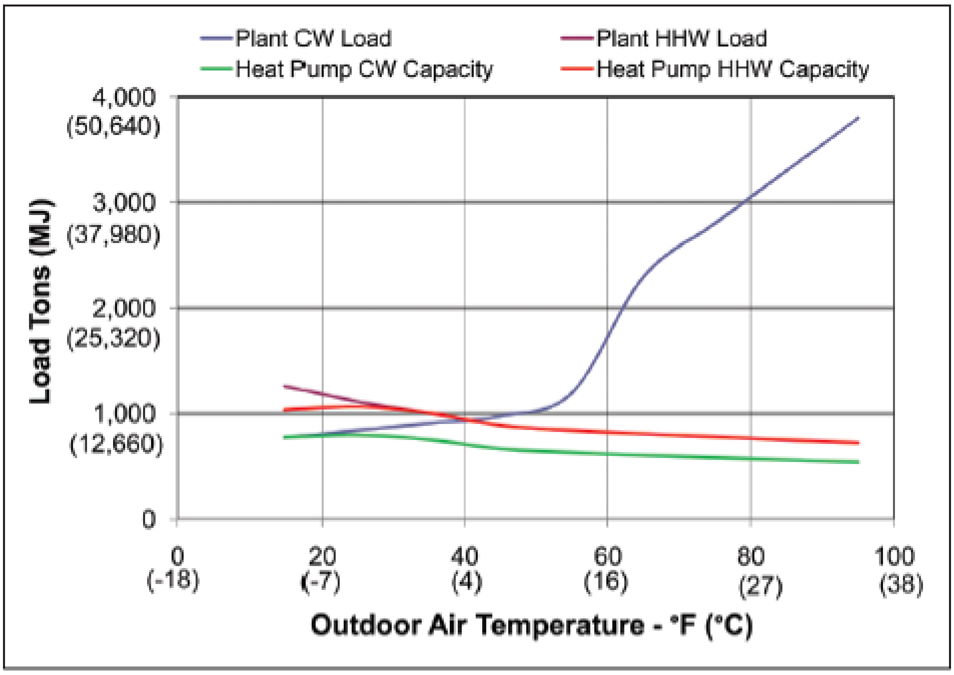
Define needs and reduce the demand

Reduction of primary cooling needs by replacing equipment producing more waste heat than needed

- If the primary needs can be reduced by selecting other machining, pumps, etc. that would need less cooling in the first place, than this has to be looked upon before anything else. For instance, a significant reduction in cooling needs can be achieved by replacing over specified fixed seed pumping capacity by demand driven (VFD) pump capacity.
- Avoidance or reduction of cutting fluids
- Technologies such as minimum quantity lubrication and cryogenic cutting[37] can be implemented where possible. If not, a reduction of cutting fluids can be achieved by means of the optimisation of the spray nozzles or the reduction of the cutting fluid pressure for internally cooled drilling and milling.
- Optimisation of downtime management
- The cutting fluid supply continues during downtime in order to maintain a constant temperature. Thanks to optimising the restart process and improved scheduling, temporary shutdowns become possible[38].
- Reduction of temperature specifications where possible
- In the case of large temperature differences between the cutting fluid and its surroundings, the cost of the re-cooling process increases significantly. Using oil-based cutting fluids allows the adjustment of the process temperature to room conditions.
- Monitoring of cooling demand in relation to outdoor air temperature
- The total cooling need of the factory is not always the sum of all potential maximum cooling needs. Monitoring the cooling need over time and identifying where cooling needs are to be added up and where they can be flattened out by shifting over time (Figure 3.5) allows reducing the peak cooling load. Moreover, certain processes are largely dependent on the outdoor temperature, while others are almost independent of it.

[37] For further information see BEMP 4.2
[38] For further information see BEMP 4.4

Figure 3.5. Plant and heat pump load (Heemer et al., 2011)



Audit

After the identification of the needs, including the reduction of the cooling demand as much as possible, an audit or assessment of the cooling system currently in place need to be performed to compare the defined needs with the current cooling installation.

One important aspect to also consider in this audit is the amount of refrigerant that needs to be added every year to the cooling system (if applicable), because that would equal a leakage of that amount of refrigerant. This is important on environmental terms because refrigerants are often very powerful greenhouse gases.

(Re)design

After the audit step, the cooling system can be (re)designed with a focus on maximising energy and water efficiency and minimising greenhouse gas emissions[39]:

- Avoid all over-dimensioning of the cooling circuit equipment.
- When designing the system, give priority to cooling optimisation at the machine level instead of cooling optimisation at the plant level.
- In case of centralised cooling systems for several machines or processes, exploit the potential for system optimisation.
- Avoid designing the system based on 'standard' cooling equipment. The most energy and water efficient solutions are those most adapted to the specific case.
- Exploit all opportunities for free cooling[40]: depending on the location of the plant during part or all of the year it may be possible to benefit from the outdoor temperature for process cooling instead of using a refrigeration cycle.

[39] Further information on different cooling techniques can also be found in the Best Available Techniques Reference Document (BREF) on Industrial Cooling Systems (European Commission, 2001). See also BEMP 2.7 on the link to the relevant BREFs.

[40] Further information on free cooling can be found in the Best Available Techniques Reference Document (BREF) on Energy Efficiency (European Commission, 2009). Additionally, see also BEMP 2.7 on the link to the relevant BREFs.

- Consider the possibility of using absorption chillers to use some of the waste heat as a source of cooling.
- Select the optimal cooling tower system. Trade-offs are to be made between energy efficiency, water saving and noise reduction. In general, axial fan equipment is more energy efficient then radial fan configurations; noise-wise the opposite is true. Table 3.4 gives an overview of the advantages and disadvantages of different types of cooling towers.
- Select the most environmentally friendly refrigerant by considering the trade-offs between the use of natural refrigerants and the lowest energy use (the Total Equivalent Warming Impact (TEWI) indicator can support this selection).
- If possible, open water cooling systems are avoided: in case the cooling water is contaminated, it would require energy intensive treatment.

The most efficient cooling towers are hybrid architectures and include controls directing the cooling water to a closed air cooled heat exchanger, to an open cooling tower or sequentially to both.

Hybrid cooling systems offer different operation modes for dry, adiabatic and wet-dry cooling and are very efficient cooling systems.

Table 3.4. Different type of cooling towers and their advantages and disadvantages, (based on Baltimore Aircoil, 2015; Seattle Public Utilities, 2015; US Department of Energy, 2011)

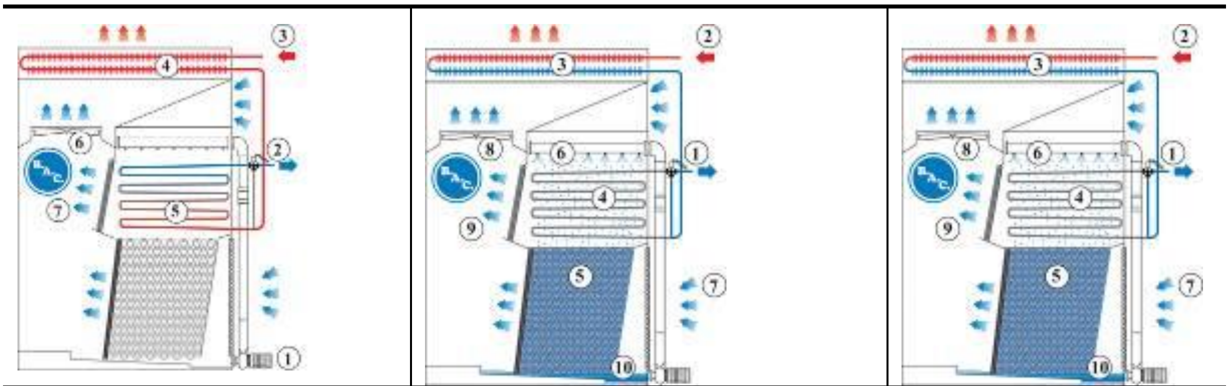
	Energy use	***Noise level***	***Operational safety (Hygiene)***	***Water use***
Fan type				
Axial fan (forced draft)	more efficient fan types	Reduced speed and specific fan configuration to reduce noise reduce also the energy efficiency		
Radial fan (induced draft)	less efficient fan types	easier to reduce noise (by using intake and discharge sound attenuators)		
Cooling tower Architecture				
Counter flow			in general more difficult to access tank for cleaning and maintenance	
Cross flow			in general easier to access fill for cleaning and maintenance	
Cooling system architecture				
Open system		in general more noisy due to sound of falling water	high risk	low potential for water saving

	Energy use	*Noise level*	*Operational safety (Hygiene)*	*Water use*
Closed system		potentially lower noise	low risk	higher potential for water savings

Adiabatic cooling has the following advantages:

- Highly efficient air pre-cooling giving up to 40% additional capacity over a fully dry air cooled alternative (Baltimore Aircoil, 2015):
- Up to 80% humidification of air compared with industry's norm of 50-70%;
- Once-through, minimum flow water system with no scaling, corrosion or microbiological growth potential and so no requirement for water treatment;
- Year round lower condensing temperatures using pre-cooling mode only when needed, saving chiller power and reducing emissions;
- Low noise levels;
- No use of toxic chemicals;
- Water savings of at least 70% compared with cooling towers;
- No potential for legionella proliferation and no generation of aerosols or water droplets thus avoiding any risk of legionellosis.

Figure 3.6. Hybrid systems offers different operation mode: for dry, adiabatic and wet-dry cooling (Baltimore Aircoil, 2015)



Dry cooling	Adiabatic cooling	Wet-dry operation
Cooling the liquid by the dry finned coil (2) for example in winter conditions when the outside temperature allows dry cooling.	The fluid is cooled in the dry finned coil (2) but the air flowing over this dry coil is saturated with water which increases the cooling capacity. This is often possible in the spring and autumn weather conditions.	In summer the fluid can be pre-cooled through the finned top coil (2) and cooled through evaporative cooling in the wet coils (3).

Achieved environmental benefits

The measures described in this BEMP typically result in energy savings, in some water savings and in a significant avoided contribution to global warming from the cooling system. The latter is not only due to the reduced energy use but also from reduced emissions of refrigerants or the switch to low GWP (global warming potential) refrigerant. Indeed, many of the refrigerants used in cooling circuits directly contribute to global warming due to their inherent GWP (see indicators section below), which is often several orders of magnitude higher than that of CO_2 (UBA, 2015).

In terms of energy, as an example, in the Bosch metal cutting departments in Feuerbach and Bamberg, the systematic implementation of the approach described in this BEMP resulted in energy savings of 4,000 MWh per year (Energiewende180, 2015).

By using less water, the environmental impacts of the water treatment are also reduced. For instance, in open cooling systems, a lower water volume means less water to be softened, filtered, etc.

The noise level of the system can also be reduced significantly at the same time of applying the energy efficiency improvements, benefiting wildlife (especially relevant in case of night operations), but also employees as well as other actors like neighbouring companies and households.

Appropriate environmental performance indicators

The following indicators can be used to monitor progress and improvements in the cooling system of a manufacturing plant:

- Global warming potential (GWP) of refrigerants used (CO_{2e})
- Total equivalent warming impact (TEWI) of the cooling system (CO_{2e})
- Energy use for cooling (kWh/year; kWh/kg finished product or manufactured part)
- Water use (tap water / rain water / surface water) for cooling (m^3/year; m^3/kg finished product or manufactured part)

Global warming potential (GWP)

This metric express the extent to which different gases contribute directly to global warming when in the atmosphere by absorbing the infrared radiation emitted by the Earth. It is a useful metric for comparing the potential climate impact of the direct emissions of different greenhouse gases (Forster & Ramaswamy 2007). Table 3.5 shows the GWP values for some refrigerants which are commonly used in cooling circuits.

Table 3.5. GWP values for refrigerants (Forster & Ramaswamy 2007).

refrigerant	type	name/ composition	GWP value
R134a	HFC	1,1,1,2-Tetrafluorethan	1430
R410A	HFC-Blend	Blend of R32 und R125	2087,5
R1234yf	HFC	2,3,3,3,Tetrafluorprop-1-en	4
R290	FC	propane	3,3
R717	natural refrigerant	ammonia	0
R718	natural refrigerant	water	0
R723	natural refrigerant	Blend of dimetylether and ammoniac	8
R744	natural refrigerant	CO_2	1

Total equivalent warming impact (TEWI)

A more appropriate measure of the refrigerant's contribution to global warming is based on the concept called total equivalent warming impact (TEWI). This value takes into consideration both the direct factor of release of the gas into the atmosphere and the indirect factor of the manufacture and lifetime operation of the system in which the gas is used.

TEWI can be calculated using the equation below (UNIDO 2009):

$$TEWI = \text{direct emissions} + \text{indirect emissions} = (GWP \times L \times N) + (Ea \times \beta \times n)$$

where L = annual refrigerant leakage rate in the system (e.g. 3% of refrigerant charge annually),

N – life of the system (e.g. 15 years),

n – system running time (based on weather data, e.g. 4910 hours/year),

Ea – energy consumption (kWh per year),

β – carbon dioxide emission factor, CO2-eq. emissions per kWh of energy.

Based on a number of assumptions and modelled energy use, Makhnatcha and Khodabandeha (2014) have calculated the TEWI for different refrigerant options in a 30 kW air/water heat pump case study and the respective share of the direct emissions contribution (Table 3.6).

Table 3.6: TEWI values for different refrigerants used in a 30 kW air/water heat pump (Makhnatcha and Khodabandeha, 2014).

Refrigerant	R290	R1270	R1234yf	R152a	R410A
TEWI, kg CO_2-eq	37,775	37,706	40,027	37,522	43,351
Direct emissions contribution to total TEWI %	0.01	0.00	0.02	0.54	9.42

Cross-media effects

The measures described in this BEMP intend to reduce energy use, water use and emissions of greenhouse gases and in fact do not have negative impacts on other environmental pressures. As explained in the "environmental benefits" section, the improvement of these dimensions is typically aligned with further environmental benefits, such as noise reduction.

Certain cross-media effects can however result from the operation of cooling system, irrespective of the specific measures described in this BEMP. Some examples are:

- when operating open or semi-open cooling circuits, contamination with the bacterium Legionella pneumophila can occur (e.g. if water temperature in the cooling tower between 25°C and 50°C; pH value between 6 and 8; occurrence of fouling - European Commission, 2001) if bacterial growth is not controlled and treated with biocides if necessary;
- significant water use can be a concern when operating open-circuit cooling towers;
- evaporative cooling system cannot function without exhausting the continuous supply of air from the air conditioned area to the outside. Released water vapour may have negative impacts on local weather.

Operational data

Further technical information in details on cooling systems in manufacturing sites can be found at the report of **Best Environmental Management Practices for Electrical and Electronic Equipment manufacturing sector**[41].

Other relevant examples and detailed technical information on how to set up a cooling system in manufacturing plants can be found at these two reports developed for the European Commission's DG Enterprise[42].

Case study, METAPLAST Gear Technology (Hungary)

METAPLAST Gear Technology, a manufacturer of high precision gears, based in Hungary, has installed a water coolant condensation for two machines that require similar temperature conditions. Water vapour is released out of the building with a chimney. METAPLAST benefits from the water coolant condensation technology because no waste heat is produced both in winter and in summer. In addition, this measure resulted in reduced noise levels (METAPLAST Gear Technology, 2017).

Applicability

The measures described in this BEMP are broadly applicable to all types of companies in this sector, including SMEs. It is more suitable for new built or renovated production lines.

In large plants technical support from external partners may be needed, which may constitute a limiting factor for the implementation of this BEMP, especially in SMEs.

Evaporative cooling systems work best in areas with low relative humidity levels. In drier climates, evaporative cooling can usually reduce energy use and total equipment costs compared to compressor-based cooling. However, even in humid environments, an evaporative cooler can still lower the temperature a few degrees below ambient temperature (Environmental Expert, 2017).

Absorption chillers are specifically suitable only when there is no heat demand for large amounts of heat (and, if these are waste heat, they cannot be reduced in the first place); otherwise, the efficiency is usually below that of conventional cooling units.

Economics

Most of the specific measures that can be implemented as a result of implementing this BEMP can be evaluated as separate investments. However, it is important to keep the whole picture in mind assuring that economic benefits are maximised over the entire system and over the entire life time of the equipment and system installed. For instance, the investment for hybrid cooling systems is significantly larger than for dry coolers, but

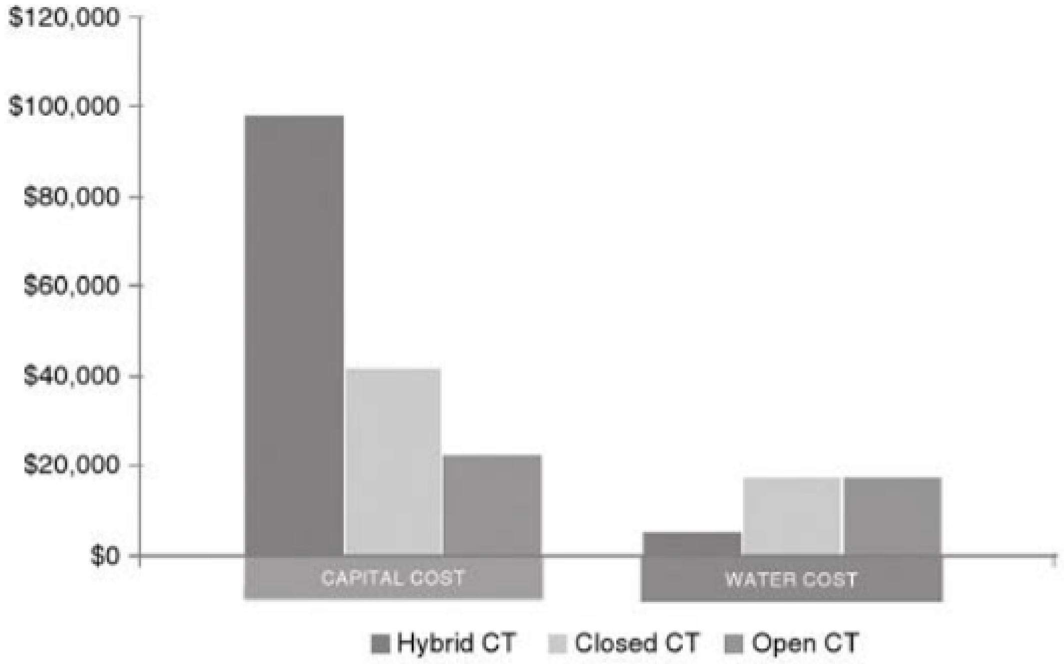
[41] This report can be found at: http://susproc.jrc.ec.europa.eu/activities/emas/eeem.html

[42] ENTR Lot 6, Product Definition, Standards and Legislation Ventilation Systems for non-residential and collective residential applications, Lot 6: Air conditioning and ventilation systems, Contract No ENTR/2009/035/LOT6/SI2.549494, prepared by VHK with ARMINES and BRE, 14 June 2012, available online at: http://www.eup-network.de/fileadmin/user_upload/Produktgruppen/Lots/Working_Documents/Task_1_Lot_6_Ventilation_Final_Report.pdf.

Ventilation products regulations based on Ecodesign directive ongoing study Ecodesign ENTR Lot 6 (Tasks 1-5), Rene Kemna, REHVA technical Seminar on buildings related EU regulations and projects, Brussels 27.10.2011, available online at: http://www.rehva.eu/fileadmin/events/eventspdf/REHVA_seminar_-_Buildings_Rel_Brussels__27.10.2011/ventilation-products-regulations-based-on-ecodesign-directive-ongoing-study-ecodesign-entr-lot-6.pdf.

the water costs are lower (see an example in Figure 3.7). This usually happens in new built manufacturing facilities and in renovated production lines (Seneviratne M., 2007 ; based on data of Baltimore Aircoil).

Figure 3.7. Cost comparison between hybrid cooling towers and conventional wet cooling systems[43] (Seneviratne M., 2007 ; based on data of Baltimore Aircoil).



For the Metaplast manufacturing site in Hungary, the installation of a water coolant condensation system for two machines the costs were approximately 5,200 EUR. Additionally, the installation of the coolant system did not require any additional permits from the authorities, which was an element to keep the costs lower. Due to the reduced need for cooling during summer, the payback time of this investment was relatively short 3–4 years (METAPLAST Gear Technology, 2017).

Driving force for implementation

The main driving forces for implementation are:

- Energy savings;
- Water savings, especially in water scarce areas;

Reference organisations

Robert Bosch GmbH (Germany): Reduced energy in metal cutting facilities by optimising cooling in Feuerbach and Bamberg (Energiewende180, 2015).

METAPLAST Gear Technology (Hungary): installed a water coolant condensation system, (personal communication with Orsolya Mallár-Varga, 2017).

[43] The comparison is based on a cooling load of 2 030 KW, an inlet temperature of 40°C, an outlet temperature of 30°C and a wet bulb temperature of 274°C

Volkswagen AG (Germany): Installed VFD drives in order to reduce energy at Sazlgitter manufacturing site (Grundfos, 2015).

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3.4 Rational and efficient use of compressed air systems

SUMMARY OVERVIEW

BEMP is for fabricated metal product manufacturers to reduce their energy consumption associated with the use of compressed air in the manufacturing processes by the following measures:

- Mapping and assessing the use of compressed air. When part of the compressed air is used in inefficient applications or in an inappropriate manner, other technological solutions may be more fit for purpose or more efficient. In case a switch from pneumatic tools to electricity-driven tools for a certain application is considered, a proper assessment, considering not just energy consumption but all environmental aspects as well as the specific needs of the application, needs to be carried out.

Optimising the compressed air system by:

- identifying and eliminating leaks, using suitable control technology, such as ultrasound measuring instruments for air leaks that are hidden or difficult to access, — better matching of the supply and demand of compressed air within the manufacturing facility, i.e. matching the air pressure, volume and quality to the needs of the various end-use devices and, when appropriate, producing the compressed air closer to the consumption centres by choosing decentralised units rather than a large centralised compressor catering for all uses,
- producing the compressed air at a lower pressure by decreasing the pressure losses in the distribution network and, when needed, adding pressure boosters only for devices that require higher pressure than most applications,
- designing the compressed air system based on the annual load duration curve, in order to ensure supply with the minimum energy use over base, peak and minimal loads,
- selecting highly efficient components for the compressed air system, such as highly efficient compressors, variable frequency drives and air dryers with integrated cold storage,
- once all of the above is optimised, recovering the heat from the compressor(s) through the installation of a plate heat exchanger within the oil circuit of the compressors; the recovered heat can be employed in a variety of applications, such as the drying of products, regeneration of the desiccant dryer, space heating, cooling thanks to the operation of an absorption chiller or converting the recovered heat into mechanical energy using Organic Rankine Cycle (ORC) machines.

Relevant stages					
Cross cutting		**Optimisation of utilities**		Manufacturing	
Main environmental benefits					
Resource efficiency	Water	Waste	Emissions to air	**Energy and climate change**	Biodiversity

Environmental performance indicators

- Electricity use per standard cubic meter of compressed air delivered at the point of end-use (kWh/m3) at a stated pressure level

- Air leakage index which is calculated when all air consumers are switched off as the sum for each of the compressors of the time it runs multiplied by the capacity of that compressor, divided by the total standby time and the total rated capacity of the compressors in the system:

$$Air\ Leakage\ Index = \frac{\sum_i t_{i(cr)} * C_{i(cr)}}{t_{(sb)} * C_{(tot)}}$$

Applicability	This BEMP is applicable to all types of companies in this sector, including SMEs. It is more suitable for new or renovated production lines.

Benchmarks of excellence	The electricity use of the compressed air system is lower than 0.11 kWh/m³ of delivered compressed air, for large installations working at 6.5 bars effective, with volume flow normalized on 1013 mbar and 20°C, and pressure deviations not exceeding 0.2 bars effective. After all air consumers are switched off, the network pressure remains stable and the compressors (on standby) do not switch to load condition.
Related BEMPs	2.3, 2.7

Description

Compressed air is a widely applied technology. It can be used both as an energy carrier (e.g. "energy air" used to power pneumatic tools) and as a process enabler (e.g. "dynamic air" to transport materials or "process air" to provide oxygen to an industrial process).

Compressed air is highly useful for manufacturers of fabricated metal products and nearly all companies make use of it, mostly as energy carrier. The advantages of compressed air lie in the inherent safety of this energy source, as well as the speed, precision, durability, low weight and small size of air tools.

The compressed air system is responsible for between 10 and 30% of the energy use of a fabricated metal products manufacturing plant (Energie Agentur, 2015). It is thus very relevant for manufacturers of fabricated metal products to make efforts to reduce this energy use.

The first step is mapping where and how the compressed air is used. If part of the compressed air is used in inefficient applications or in an inappropriate manner, other solutions are better fit for purpose (e.g. removing waste using a vacuum device). Table 3.7 (EREE, 2004) provides some examples of inappropriate use of compressed air and suggests alternative methods. Especially the low-pressure uses of compressed air should be looked at carefully (EREE, 2004).

Table 3.7. Overview of the most common types of inappropriate use of compressed air in the Fabricated Metal Products Sector (EREE, 2004)

Potentially inappropriate uses	*Examples within the Fabricated Metal Products sector*	*Suggested alternatives/ actions*	*Remarks*
Open blowing, mixing, drying, cooling, atomizing, padding, etc.	Cleaning of machines or finished parts, cooling after heat treatment, drying after wet process steps, airbrushes, paint sprayers, air gages, aerating/agitating equipment, cooling in welding equipment, etc.	Fans, blower, mixers, nozzles	Open-blowing applications waste compressed air. For existing open-blowing applications, high efficiency nozzles could be applied, or if high-pressure air isn't needed, consider a blower or a fan. Mechanical methods of mixing typically use less energy than compressed air.
Parts cleaning and sparring	Cleaning burrs, turnings, sandblasting, etc.	Brushes, blowers, vacuum pumps	Low-pressure blowers, electric fans, brooms, and high-efficiency nozzles are more efficient for parts cleaning than using compressed air to accomplish such tasks.
Vacuum generator	Vacuum based tools used for material handling, automation, vacuum clamping fixtures and jigs, etc.	Dedicated vacuum pump or central vacuum system	
Air motors and air pumps	Pneumatic grinders, ratchets, jacks, drills, hammers, riveters, etc.	Electric motors, mechanical pumps	The tasks performed by air motors can usually be done more efficiently by an electric motor. Similarly, mechanical pumps are more efficient than air-operated double diaphragm pumps. However, in hazardous environments (e.g. explosive atmospheres) compressed air might be an appropriate and safe choice. If air motors and pumps are used, proper regulator and speed control are needed
Idle equipment		Put an air-stop valve at the compressed air inlet	Equipment that is temporarily not in use during the production cycle.
Abandoned equipment		Disconnect air supply to equipment	Equipment that is no longer in use either due to a process change or malfunction.

Some manufacturers of fabricated metal products decide switching, for certain applications, from pneumatic tools to electricity-driven tools. This allows reducing the overall energy use provided that the efficiency of the electrical tool is higher than the combined efficiency of the compressed air system (generation + distribution) and of the pneumatic tool (Niermeier 2013). However, the choice between pneumatic tools and electricity-driven tools must be based on the state of the art technology, and not necessarily on existing installations, and on their functionality for the manufacturing processes carried out within the site, considering all environmental pressures (not only energy use).

Companies of the sector need to carry out a proper assessment on a case-by-case basis, considering not just energy use but all environmental aspects as well as the specific needs of the application being considered, taking into account the advantages of pneumatic tools. Some of these are:

- durability - in general, compressed air tools have a longer life compared to electrically driven tools;
- compact size - pneumatic tools are usually smaller and can make possible to drill holes or tighten fasters in places which cannot be accessed by bulkier electric tools;
- suitability for high loading and clamping operations: compressed air tools do not generate heat under load and can thus have lower rated power to perform the same task;
- safety in ATEX[44] environments - electrically driven tools cannot be used in a number of environments where sparks or heat cannot be produced (e.g. explosive atmosphere);
- power-to-weight size ratio: compressed air tools have a higher power-to-weight size ratio compared to electric tools, thus less efforts is needed for operators to carry out their job;
- WEEE generation - once reached their end-of-life, electrically driven tools become WEEE and, if battery-powered, the disposal of batteries is one of the main issues, while compressed air tools are much easier to recycle;
- use of critical raw materials - electrically driven tools use some critical raw materials (in motors and batteries), which is not the case for pneumatic tools.

When the use of compressed air is considered appropriate based on the mapping and assessment of its use, it is then best practice to:

- optimise the compressed air system configuration;
- choose an optimal use and control basic parameters, such as the pressure set point;
- perform appropriate maintenance for compressed air systems.

Optimisation of the compressed air system configuration

The correct set-up and configuration of a compressed air system can lead to important cost and environmental impact savings. This is valid for greenfield projects, as well as for existing plants. Table 3.8 gives an overview of some basic considerations for the design of a performant compressed air system.

[44] ATEX refers to potentially explosive atmospheres (European Commission, 2016)

Table 3.8. Overview of main measures related to compressed air system configuration

Action	Description
Use compressors with variable speed drives	Most air compressors become less energy efficient as air demand is reduced. In extreme cases, up to 65% of the rated electrical power is still used even when there is no demand for air. By purchasing a variable speed drive (VSD) compressor (Carbon Trust, 2012) or retrofitting a VSD to an existing compressor, companies can save energy and money.
Optimal control of the compressed air system	System control can consist of using simple isolated controls, such as: • Time-operated valves that control different 'zones' of the compressed air circuit; • Interlocks that allow the compressed air circuit to open only when a particular air-using machine is running; • Sensors that detect when a product is present and then open the compressed air circuit. These controls could be integrated within a building management system or a plant/process control system. Alarms can be set that indicate plant faults or when threshold limits have been reached.
Controlling multiple compressors	Where cascade pressure control is often used in industry, a more efficient method of controlling multiple compressors is via an electronic sequential controller, which can control multiple compressors around a single set pressure. These systems also make compressors available to match demand as closely as possible. This control can also predict when to start/stop or load/unload the next compressor in sequence by monitoring the decay/rise in system pressure. They can also be set to vary the pressure according to production requirements, for example, lower pressure at weekends.
Stabilising system pressure	Stabilizing system pressure (EERE, 2004) is an important way to lower energy costs and maintain reliable production and product quality. Three methods can be used to stabilize system pressure: (1) adequate primary and secondary storage; (2) Pressure/Flow Controllers (P/FCs); (3) use of dedicated compressors.
Lowering system pressure	Additional savings can be achieved by reducing the pressure level of the compressed air system. The specific electricity consumption of the system is directly correlated with its pressure level. Therefore, if the pressure level can be lowered by 1 bar, the energy demand will decrease by about 6% to 10%.
Choosing the right air quality	Higher quality air requires additional air treatment equipment, which increases capital costs as well as energy consumption and maintenance needs (EERE, 2004). The quality of air produced should be guided by the degree of dryness and filtration needed and by the minimum acceptable contaminant level to the end uses. One of the main is whether lubricant-free air is required.

Action	Description
	Lubricant-free air can be produced either by using lubricant-free compressors, or with lubricant-injected compressors and additional air treatment equipment.
Effect of intake on compressor performance	Contaminated or hot intake air can impair compressor performance and result in excess energy and maintenance costs (EERE, 2004). The location of the entry to the inlet pipe should be as free as possible from ambient contaminants (e.g. rain, dirt, discharge from a cooling tower), and inlet temperature should be kept to a minimum. All intake air should be adequately filtered.
Optimisation of distribution lines	The distribution line is often the oldest part of the company's infrastructure. Some measures to reduce energy consumption are: reduction of pipe length to reduce pressure drop (e.g. for delivering compressed air to new equipment); use localised compressors close to equipment; prevention of 90 degrees curves since they constitute a resistance for compressed air; use of ring pipe for the reduction of the system pressure; increase of pipe diameter for reduced pressure drops; adaptation of system pressure to demand; local pressure increase or decentralised generation for remaining low system pressure; displacement of pipe sections and installation of a time switch (IHK, 2012).
Consider heat recovery	About 80 to 90% of the electrical input to a compressor is lost as heat. Recovery of waste heat from air and water cooled compressors can considerably increase the overall energy efficiency of a compressed air system. Heat recovery systems (Carbon Trust, 2012; Moskowitz, 2010) are particularly beneficial for sites with demands for hot water or heating, including water, space or process heating, drying.
Select the right type of compressor technology	Basically 3 types of compressors exist: reciprocating, rotary and centrifugal compressors. Depending on the application (required pressure, volume, variability, etc.) one technology may prove more energy efficient and controllable than the other on a particular duty, and maintenance costs between the different technologies can vary considerably. Therefore, when selecting an air compressor, it is important to look at the total cost across the system, over the life cycle of the equipment.
Use of solenoid valves	Blowing nozzles and vacuum injector are uncontrollable permanent consumers, which use compressed air even during machine downtime. The consumption can be stopped by mean dos solenoid vales to ensure supply is stopped automatically after switch-off (IHK, 2012).

Optimisation of the compressed air use

Where compressed air is the energy carrier of choice, choosing an optimal use and control (basic parameters, such as the pressure set point) can save costs and environmental impacts. Table 3.9 gives a set of steps that can guide users to optimise their compressed air use (EERE, 2004; IHK, 2012).

Table 3.9. Sequence of steps that can be used to optimise the settings of compressed air systems

Step	Action
1	Review the pressure level requirements of the end-use applications. Those pressure level requirements should determine the system pressure level. Because there is often a substantial difference in air consumption and pressure levels required by similar tools available from different manufacturers, request exact figures from each manufacturer for the specific application. Do not confuse maximum allowable with required pressure.
2	Monitor the air pressure at the inlet to the tool. Improperly-sized hoses, fittings and quick disconnects often result in large pressure drops. These drops require higher system pressures to compensate, thus wasting energy. Reduced inlet pressure at the tool reduces the output from the tool and, in some cases, may require a larger tool for the specified speed and torque.
3	Avoid the operation of any air tool at "free speed" with no load. Operating a tool this way will consume more air than a tool that has the load applied.
4	End uses having similar air requirements of pressure and air quality may be grouped in reasonably close proximity, allowing a minimum of distribution piping, air treatment and controls.
5	Investigate and, if possible, reduce the highest point-of-use pressure requirements. Then, adjust the system pressure.

Appropriate maintenance for compressed air systems

Like for most energy using equipment, proper maintenance is paramount to assure reliable and energy-efficient performance. Table 3.10 lists the main types of maintenance actions (EERE, 2004).

Table 3.10. Considerations for optimal maintenance of compressed air systems

Action	Description
Leak reduction	All compressed air systems have leaks, even new ones. A continuous effort to reduce air leaks will lead to important energy savings and carrying out a baseline analysis to understand the relevance of leakages can be a first relevant action. Around 15 to 60% of the created air can be lost due to leakages. The sources of leakage are numerous, but the most frequent causes are: manual condensate drain valves left open; failed auto drain valves; shut-off valves left open; leaking hoses and couplings; leaking pipes, flanges and pipe joints; strained flexible hoses; leaking pressure regulators; air-using equipment left in operation when not needed. Besides listening and using a soapy water solution or a leakage spray, ultrasonic leak detection equipment can be used. Routinely check compressed air systems for leaks.
Implementation of preventive maintenance plan	Like all electro-mechanical equipment, industrial compressed air systems require periodic maintenance to operate at peak efficiency and minimize unscheduled downtime. Inadequate maintenance can increase energy consumption via lower compression efficiency, air leakage or pressure variability. It also can lead to high operating temperatures, poor

Action	Description
	moisture control, excessive contamination, and unsafe working environments. Some very handy templates for maintenance plans and checklist are available.
Appropriate removal of condensate	Removing condensate (EERE, 2004) is important for maintaining the appropriate air quality level required by end uses. However, significant compressed air (and energy) losses can occur if condensate removal is done improperly. Drain the condensate often and in smaller quantities rather than less frequently and in larger quantities. Consider oversized condensate treatment equipment to handle unexpected lubricant loading and to reduce maintenance. Consider using zero loss drain traps.
Replace tools in time	Check the useful life of each end-use application. A worn tool will often require higher pressure and consume excess compressed air.
Lubricate properly	Air tools should be lubricated as specified by the manufacturer.

Achieved environmental benefits

The energy use of tools and machines is a dominant factor in the total environmental impact that generally outweighs other life cycle stages like production of the equipment, logistics and end-of-life. Typically, only 17% of the total energy supplied to the compressor is converted into usable energy. Electric tools generally only need 10 to 30% of the energy that pneumatic tools use for the same operation and can lead to up to 90% energy savings when used to substitute compressed air operated (Niermeier, 2013).

Not only the selection of another energy carrier, but also the optimisation of the configuration, use and maintenance of compressed air systems can lead to considerable cost and energy savings. The potential of energy savings evidently depends on the current use and performance of the compressed air systems. Savings of 40% and more are regularly reported in industrial companies, attained without large investments (Table 3.11).

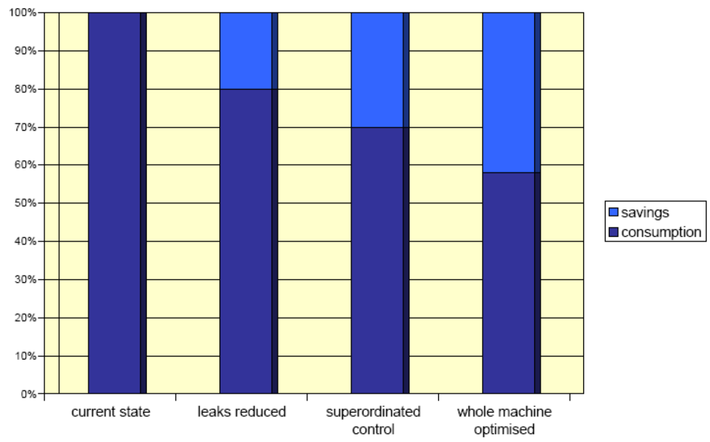
Because of the specific context of each manufacturing plant, the starting position and the multitude of possible actions, it is difficult to estimate or project the potential overall savings in environmental impacts in general. Table 3.11 and Figure 3.8 give some indications and examples of the potential savings related to optimized use of compressed air.

Table 3.11. Examples of achievable energy saving through compressed air measures in an industrial context (Carbon Trust, 2012)

Action	Potential Energy saving
Reduce the average air intake temperature	A reduction of the air intake temperature with 4°C leads to a 1% energy saving.
Leak reduction	Eliminating a leak of 1 mm² in a compressed air system operating at 6 bar leads to an energy saving of 15 MWh per year.
Optimisation of the usage	Even when idling, compressors can consume between

Action	Potential Energy saving
regime of compressed air systems	20-70% of their full load power.
Reduce the pressure of the compressed air system to the minimal pressure required	For a typical screw compressor operating at 7 bar, every reduction of the pressure with 0.5 bar will lead to an energy saving of 3-4%.
Waste energy recovery	Up to 80% of the energy used in compressing air can be used, for example in low-grade space heating, conversion into hot water or preheating boiler water. Waste recovery in general requires some investments.
Optimised maintenance	Tests carried out on over 300 typical compressors show that energy savings of 10% can be achieved through low-cost maintenance activities. So, in addition to improving reliability, maintenance can also save energy and money.

Figure 3.8. Potential saving related to compressed air (Ceati, 2007)



In general, the optimisation of compressed air systems shows a total energy saving potential of 30%. For SMEs an energy saving potential of up to 50% has been determined (IHK, 2012).

Appropriate environmental performance indicators

The indicators of this BEMP are listed below:

- Electricity use per standard cubic meter of compressed air delivered at the point of end-use (kWh/m^3) at a stated pressure level
- Air leakage index, which is calculated when all air consumers are switched off as the sum for each of the compressors of the time it runs multiplied by the capacity of that compressor, divided by the total standby time and the total rated capacity of the compressors in the system.

The air leakage index is calculated by the following equation:

$$Air\ Leakage\ Index = \frac{\sum_i t_{i(cr)} * C_{i(cr)}}{t_{(sb)} * C_{(tot)}}$$

where:

$t_{i(cr)}$ is the time (min) during which a compressor runs when all air consumers are switched off (standby of the compressed air system);

$C_{i(cr)}$ is the capacity (Nl/min) of the compressor that switches on for the time $t_{i(cr)}$ while all air consumers are switched off;

$t_{(sb)}$ is the total time (min) during which the installed compressed air equipment is in standby mode;

$C_{(tot)}$ is sum of the rated capacity (Nl/min) of all the compressors in the compressed air system.

The value of the air leakage index provides an indication on the significance of the air leakages in the system. Values closer to zero mean lower leaks. In fact, after all air consumers are switched off the network pressure should remain stable (if there are no leaks), and the compressors in stand-by should not switch to load condition. If there are leaks, the network pressure will decrease, and when the minimum pressure is reached at least one compressor switches to load and delivers compressed air to bring the network back to the pressure set. This can happen several times over the period of stand-by. It is recommended to calculate the index over the same time span e.g. 8 hours in order to ensure comparability among the various measurements. Also, it is recommended to use this indicator only when the same compressed air system is tested[45] or when identic or very similar installations work under the same operating conditions.

Cross-media effects

The measures related to optimisation of the configuration, use and maintenance of compressed air systems usually have no negative effects on other environmental compartments. In the case of large investments (improved compressor technology, alternative energy carrier), there is an environmental impact related to the production and end-of-life of the tools and machines.

When compressed air tools are replaced (where and when feasible) by electric tools using batteries, it has to be taken into account that electric motors usually require the use of critical metals in their magnets, especially neodymium. Neodymium is regarded as "critical raw material" in the EU; furthermore, its extraction is associated with heavy burden on the local environment (European Commission 2014; Schüler et al. 2011).

Additionally, the adoption of electrically driven devices instead of compressed air tools causes the generation of WEEE when the tools and batteries reach their end of life, while compressed air tools are typically easier to handle and recycle at their end of life.

Operational data

Some of the measures already mentioned in Tables 3.9 – 3.11 regarding the optimisation of the use of compressed air are further looked at in the following paragraphs by presenting certain specific examples from companies that have already implemented those measures.

[45] As regards to the operating and testing conditions, manufacturers can also refer to the ISO standard 1217:2009, which specifies methods for testing liquid-ring type compressors and the operating and testing conditions which apply when a full performance test is specified.

Map and assess the use of compressed air

In the first instance, it is very important that companies analyse where and how compressed air is used, by:

- Creating an inventory of the needs of end uses in terms of air pressure needed, volume and quantity
- Identifying inappropriate uses of compressed air as listed in the Description section
- Assessing potential energy savings by comparing the use of pneumatic tools with electric tools

Bombardier (a producer of trains) reduced its compressed air consumption by a quarter. The same company did flow measurements to map its consumption profile. As the demand for compressed air lowered, it could replace big compressors by smaller, more efficient ones (Encon, 2015).

Optimisation of distribution lines

The pressure drop within the distribution lines depends on the pipe length, pipe diameter and leaks.

By increasing the pressure in the compressed air system (8 bars) the energy costs increase by 6 to 10%. A pressure drop from 6 to 5 bars can lead to a decrease of performance of tools and installations by 30%. Furthermore, it can be stated that the pressure drop from the compressor to the end user should not exceed 0.1 bar (LfU).

For reducing the pressure drops the following actions can be taken:

- eliminate bottlenecks
- choose quick coupling and ball valves with high flow capacity
- choose pipes with adequate diameters
- lay straight pipes
- use Y-sections and arches instead of knee and T-pieces
- extend a stub line with a loop line

Reduction of leakages

One substantial aspect for the reduction of energy use is the identification of leakages as stated in Table 3.12. Leakages in the compressed air system can lead to energy losses up to 80% (Almig, 2017).

Table 3.12. Air and power losses and related costs caused by air leaks of different sizes (source: own table according to data from VDMA stated by Almig, 2017)

Diameter of the air leak (mm)	*Air losses (l/s) at 6 bars*	*Air losses (l/s) at 12 bars*	*Power losses (kW) at 6 bars*	*Power losses (kW) at 12 bars*
1	1.2	1.8	0.3	1.0
3	11.1	20.8	3.1	12.7
5	30.9	58.5	8.3	33.7
10	123.8	235.2	33.0	132.0

Therefore, the identification of the amount of leakage losses and the location of leakages are crucial to investigate.

Adequate techniques for the measurement of the leakage losses are the following:

- Identification of leakages by deflation of the pressure tank
- Identification of leakages by compressor running times
- Identification of leakages by compressed air consumption measurement

Measures to locate air leaks in general are soaping of the compressed air connection, noise generation and ultrasonic measurement (Almig, 2017).

Applicability

The design (configuration), operation and maintenance of compressed air systems can be optimised in every type of company in the sector, including SMEs. However, the energy saving potential largely depends on the plant specificity and its current situation. Major changes to the compressed air system (e.g. change the layout of compressed air distribution lines) can be adopted only when the installation is renovated and subject to substantial intervention.

Especially measures that require only small investments such as leak reduction, optimized maintenance and reduced pressure of the compressed air system to the minimal pressure required can increase the overall energy efficiency and can easily be applied by SMEs.

The identification of leaks in the compressed air system can be considered highly applicable for SMEs and affordable since the majority of leaks (approx. 70%) is located on the last 30% of the system (Almig, 2017).

The applicability of valves that stop the supply of compressed air needs to be taken into consideration. Examples have shown that separate manual valves to close the supply of compressed air have not shown the desired energy savings since workers have not closed the valves when stopping the machines. Therefore, a SME needs good training of workers and high reliability. A better solution might be the installation of a solenoid valve which ensures that the supply is stopped automatically every time when the machine is switched off. This can result in significant savings.

Economics

Many of the described energy saving measures for compressed air systems can be done without large investments, and often have a reasonably short payback period (DoE reported a median payback period of 18 months for measures other than compressor changes). Only for more drastic changes (e.g. implementation of other technologies instead of compressed air, replacement of a compressor) investment may be higher and payback period may be longer. As reported above, the optimisation of the distribution lines can lead to reduced pressure drops. The following table summarises the investment costs in comparison to energy costs for the compensation of the pressure loss in relation to the diameter of the pipes. It shows that a higher investment can prevent from higher operational costs caused by higher pressure drops.

Table 3.13. Investment costs and energy costs for pressure drop compensation in relation to pipe diameters and pressure drop (source: own table according to data from LfU)

Internal pipe diameter (mm)	*Pressure drop (bar)*	*Investment costs (€)*	*Energy costs for pressure drop compensation (€/a)*
90	0.04	10,000	150
70	0.2	7,500	600
50	0.86	3,000	3,270

The presence of leakages in a compressed air system results in significant costs. The annual energy costs caused by air leaks for systems running at 6 and 12 bar are presented in Table 3.14 (data also related to the air losses presented above in Table 3.13).

Table 3.14. Air and power losses and related costs caused by air leaks of different sizes (source: own table according to data from VDMA stated by Almig, 2017)

Diameter of the air leak (mm)	Costs (€/a) at 6 bars	Costs (€/a) at 12 bars
1	144	480
3	1,488	6,096
5	3,984	16,176
10	15,840	63,360

Driving force for implementation

The environmental performance of compressed air systems, tools and machines in the sector is largely dominated by their energy use, which is directly linked to energy costs. Consequently, both economic and environmental drivers are applicable at the same time: companies will consider applying this BEMP because of environmental concerns and/or cost drivers.

Related to the elimination of inappropriate use of compressed air, it is known that also other aspects and drivers can play a role, such as compatibility with explosion and fire hazards, cleanliness and hygiene requirements, ergonomics, ease of maintenance and durability.

Consequently, in cases where compressed air cannot be replaced by other energy sources some of the mentioned measures or ideally a combination of many should be implemented to increase the energy efficiency of the compressed air system.

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Alutec: manufacturer of alloy wheels (Accessory Division) and wheels suppliers to the automotive industry (Automotive Division).

Volvo Cars: is a truck and car producer. In their production plan in Ghent, Volvo reviewed the compressed air system (Volvo, 2012).

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3.5 Use of renewable energy

SUMMARY OVERVIEW
BEMP is for fabricated metal product manufacturing companies to use renewable energy for their processes by: • purchasing of verified renewable electricity or own generation of electricity from renewable energy sources; • generating heat from renewable energy sources (e.g. biomass, solar); • installing energy storage systems, where relevant, to enable higher rates of own use of self-generated renewable energy.

Relevant stage		
Cross cutting	**Optimisation of utilities**	Manufacturing

Main environmental benefits					
Resource efficiency	Water	Waste	Emissions to air	**Energy and climate change**	Biodiversity

Environmental performance indicators
- Share or electricity from renewable sources (self-generated or purchased) out of the total energy use (%) - Share of heat from renewable sources out of the total heat use (%)

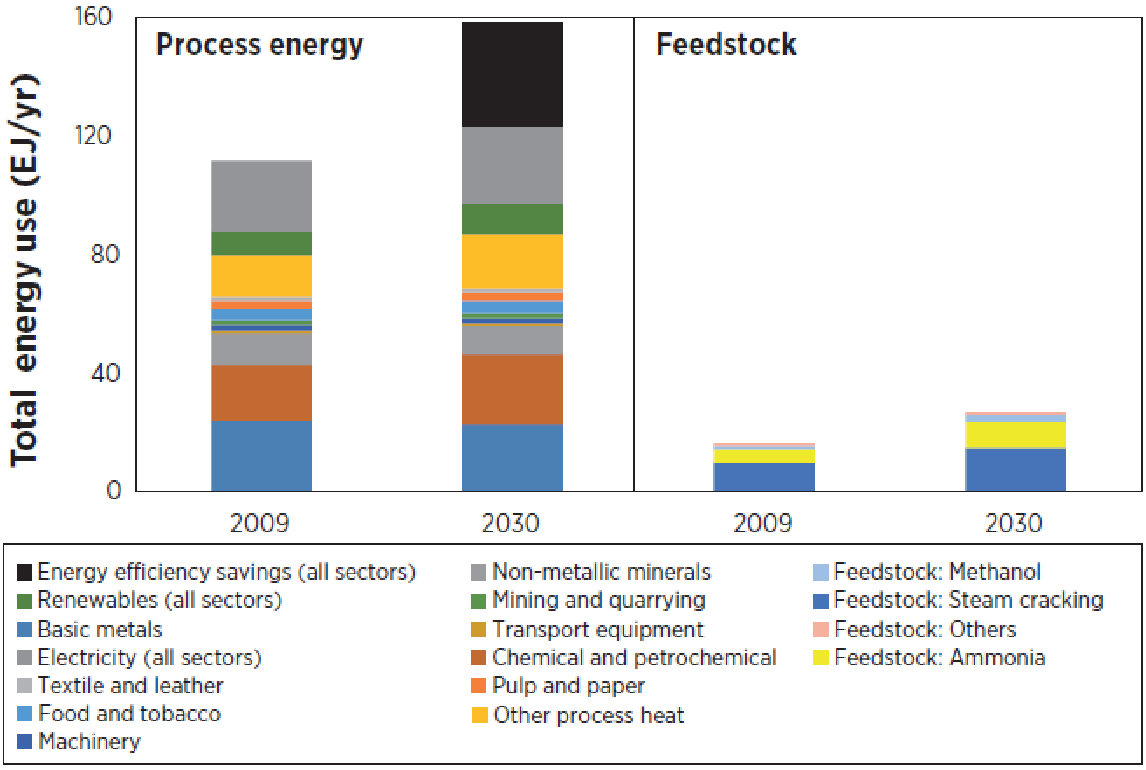
Applicability	The BEMP is broadly applicable to all types of companies in this sector, including SMEs. The own heat generation from renewables and integration in the fabrication processes, highly depends on the technological specificities of the carried out manufacturing processes and the actual demand e.g. high-temperature process.
Benchmarks of excellence	All electricity use is met by self-generated renewable energy or purchased verified renewable electricity. The use of renewable heat generated on-site is integrated in suitable manufacturing processes.
Related BEMPs	2.3

Description

Energy is used in the industrial sector for a wide range of purposes, such as process and assembly, steam and cogeneration, process heating and cooling, lighting, heating, and air conditioning for buildings and production halls (EIA, 2016).

Complex machine settings and high demands of heat and power lead to relevant total energy use. According to (UBA, 2016), the fabricated metal products manufacturing sector is responsible for about 6.5% of the total energy use in Germany. SMEs are responsible for 70% of this demand, even if a reduction is expected until 2020 due to more environmentally friendly techniques and practices (IREES, 2013).

Figure 3.9. Total final energy use in global industry with a breakdown by sector (IRENA, 2014)



The first step is always to reduce energy use as far as possible before considering fuel switching to a renewable source, even partially or completely (e.g. consult relevant BEMP 2.3 Energy management and various relevant BEMPs over the energy efficiency of several processes and utilities).

In particular, once all the possibilities for improving energy efficiency have been explored, then renewable energy can be considered as an alternative option to be used in the manufacturing plants.

Therefore, the use of renewable energy, either on/off-site generation or purchased (from renewable energy sources) is thus crucial for realising substantial reductions in the fossil fuel demand of the manufacturing sector and associated CO_2 emissions.

From an individual fabricated metal products manufacturing company perspective, switching to renewable energy may take different forms. For electricity, this can be achieved through: i) purchasing of verified "green"[46] electricity and/or ii) own generation of electricity and its storage when feasible.

Another possibility, not necessarily only for electricity but also for heat, is the exchange of different forms of energy among companies e.g. heat excess from a company is distributed to another adjacent manufacturing site. This option is generally part of the idea of the industrial symbiosis, which is further discussed in the "BEMP 2.2 Collaboration and communication along and across the value chain".

i. Purchase of green electricity

Off-site energy generated from renewable sources can be also purchased on the market either through national or regional utility suppliers or more rarely by contracting directly

[46] It can also include off-site generation of energy from renewable energy sources

with a renewable energy supplier e.g. a PV or wind farm located near the site. Most EU countries have at least one locally available energy utility offering "green" tariffs i.e. certified renewable energy contracted through the supplier but corresponding to a regular connection and distribution from the grid. Certification or assurance ensures that the contract corresponds to additional energy generation i.e. that the renewable energy is not otherwise accounted for or the credit claimed elsewhere, maximising the incentive effect for the further development of renewable energy.

ii. On-site generation and storage of energy from renewable energy sources

The on-site generation of electricity from renewable energy sources is possible through the use of the photovoltaic panels (PV), wind turbines and (sustainably sourced) biomass combustion technologies. These technologies have relevant positive effects on the environment in terms of emission abatement, deriving from the avoidance of fossil fuel consumption.

However, a share of energy use in fabricated metal products manufacturing companies is not electricity but heat. This is mainly used as process heat for a large set of processes. The use of renewable heat technologies (e.g. solar thermal energy and geothermal power) can be a great opportunity for industries depending on local conditions and availability (Carbon Trust, 2014). Several opportunities and technologies exist for the use of heat from renewable energy sources in fabricated metal products manufacturing plants from solar thermal energy. These are typically classified according to the achieved level of temperature. For instance, low temperature applications (e.g. below 100°C) are suitable for applications such as space heating and metal surface treatment and is achievable by installing e.g. a Transpired Solar Collector System. Likewise, renewable heat generation at mid temperature levels (below 250°C) is suitable for manufacturing processes e.g. cooling and air conditioning and technologies of e.g. vacuum collectors can be installed (Schweiger et al., 2000; EESI, 2011; IEA SHC, 2012; IRENA, 2015).

Depending on the local legal context, companies may import and/or export their own generated electricity to the grid i.e. the renewable energy generated sometimes is not used directly but can be counted towards the general reduction in fossil intensity of the organisation.

Additionally, manufacturers can explore the possibilities for generating, storing and distributing energy. In particular, energy storage, including mechanical, electrochemical and thermal storage technologies, can be considered as a feasible solution. The electricity storage available option consists of three steps (SBC Energy Institute, 2013):

1. Withdrawing energy from the grid
2. Storage of the energy
3. Return to the grid.

The primary purpose of energy storage is to ensure power quality and reliability of supply (Figure 3.10). A secondary purpose is related to energy requirements involving load levelling which enables storing power in times of excess supply and discharging it in times of deficits (Deloitte Development LCC, 2015).

Figure 3.10. Battery storage system (SBC Energy Institute, 2013)

The two crucial dimensions for storing energy are the power capacity of the charging and discharging phase, defining the ability of the storage system to withdraw electricity from or to the grid, and the energy capacity of the storing phase, which affects the amount of energy that can be stored over a certain period of time.

Load levelling has high relevance for the fabricated metal products manufacturing sector as well. Many processes in this sector are energy intensive due to the use of compressors, pumps, heating and cooling systems etc., leading to high peaks and lower demand in standby times. Storage systems represent an option to store solar energy in form of electricity including the technologies highlighted in Figure 3.11.

Figure 3.11. Energy storage technologies (SBC Energy Institute, 2013)

Kinetic energy			Potential energy		
Thermal technologies	Electrical technologies	Mechanical technologies		Electrochemical technologies	Chemical technologies
Hot water	Supercapacitors	Flywheels	Pumped hydro	Lithium ion	Hydrogen
Molten salt	Superconducting magnetic energy		Compressed air energy	Lead acid	Synthetic natural gas
Phase change material				Redox flow	
				Sodium sulfur	

Achieved environmental benefits

The achieved environmental benefits from on-site production of renewable energies in the fabricated metal products manufacturing sector depend on the applied technology and process-related limitations. Besides the general improvements of use of energy from renewable energy sources, compared to energy from fossil fuels, the on-site production of such systems in general minimises transport losses, especially in the case of electricity.

The use of biomass for heat and electricity production, in an optimal case represents a climate change mitigation method, as stated by the IPCC (2016). Technologies providing heat from renewable sources could abate 120 Mt of CO_2 by 2030 (IEA, 2012), which is considered to be a very important contribution in order to achieve the goals related to climate change mitigation that have been set in the Climate Contract of Paris in 2016. However, the magnitude of the positive effects strongly depends on the origin and the cultivation of the biomass, the transport conditions as well as process efficiencies.

The application of solar energy systems can contribute to the electricity and heat production of a company wherefore the share of fossil fuels can be reduced. When energy derived from fossil fuels is replaced with heat derived from solar energy, users can reduce the detrimental environmental side effects; such as the production of greenhouse gasses (plus NO_X and SO_X) associated with the burning of fossil fuels (Mendaza, 2014). Additionally, solar panels are installed on the roof of buildings to be supplied with energy so that absolutely no transport costs arise. In combination, these two factors lead to the avoidance of relevant amounts of greenhouse gas emissions.

Appropriate environmental performance indicators

The appropriate environmental performance indicators for this BEMP are:

- Share of electricity from renewable sources (self-generated or purchased) out of the total energy use (%)
- Share of heat from renewable sources out of the total heat use (%).

Cross-media effects

As an important cross-media-effect it has to be taken into account, that fabrication facilities for photovoltaic panel may adversely affect the environment by emitting pollutants during routine operation or in the case of accidental events (Fthenakis and Moskowitz, 2000). Some of the highly effective materials in the solar panels have great toxic potentials such as arsenic that is used in the manufacture of Gallium Arsenide cells. Nevertheless, due to relevant technological improvements in the production of solar panels, the positive effects of solar energy production predominate. With careful implementation, the cross-media effects arising from the utilisation of photovoltaic can be mitigated so that the overall environmental impacts will be positive. Mitigation options for solar energy systems are to maximise the output through optimised installation such as south orientation of the solar panels. A long operational lifetime through regular cleaning and maintenance must be ensured (Gaudillat et al., 2017).

Biomass is produced for energy generation purposes. This, however, stands in conflict with food production as well as with general land use development. In some countries food production systems are converted into high intensity bio-fuel fields leading to negative environmental impacts and lower food production capacities. Another cross-media effect is the transformation of formerly diverse landscapes into monocultures leading to the risk of decreased environmental stability as well as losses in biodiversity. This 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. These detrimental effects on the environment caused by the production of bio-fuels can be mitigated by using 2^{nd} and 3^{rd} generation of biofuels.

It is necessary to create the least additional burden on water and soil by producing biomass in the most possible sustainable manner to maintain overall positive effects of energy generation from biomass (IRENA, 2014). From biomass heating cross-media effects such as air pollution (local) arise. From wood burning emissions such as CO, NO_x, hydrocarbons, particles and soot to air arise and produce 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 (Gaudillat et al., 2017).

Energy use has a significant environmental impact on fabricated metal products manufacturing companies. Although a large role in mitigating these impacts can be played by improvements in energy efficiency, relying exclusively on them will not be sufficient to reduce the increasing demand of fossil fuels and their associated environmental impact (IRENA, 2014).

Operational data

One of the main practical applications for the on-site energy generation is the installation of solar panels to generate heat. This technique is based on the installation of collector panels on the roof of the buildings, or on other available surfaces of the plant, which are heated from direct solar radiation.

The following criteria are used to determine if a company is well-suited and orientated to the integration of solar thermal (Figure 3.12). The more of the following criteria apply, the greater the potential for this renewable technology (EnPro, 2017):

Local parameters

- Free roof or floor space for the installation of a solar thermal system is available.
- Orientation of the roof slopes to the south / southeast / southwest.
- Space for the installation of buffer storage is available.

Heat demand

- Process heat demand given to a significant extent that matches to the production requirements.
- Required heat utilisation temperature 90 °C.

Costs

- Careful sizing of the capacity of the solar panels to estimate the investment and installation costs against the savings from the substitution of the fossil fuels

Figure 3.12. Solar energy collectors

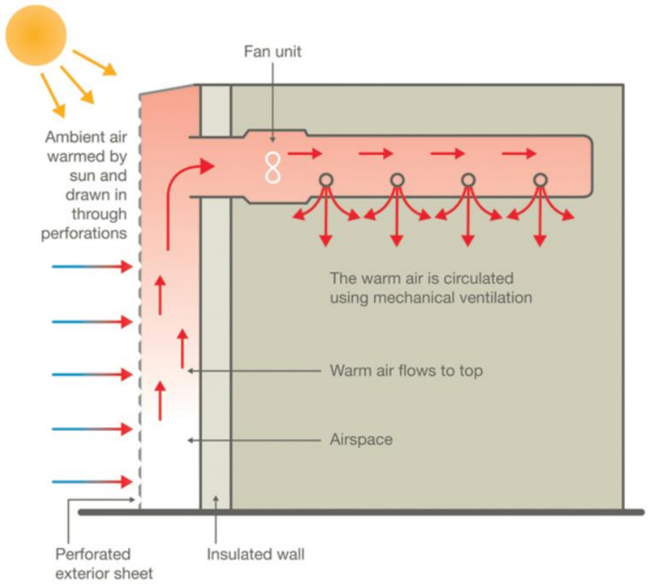
According to Lauterbach (n.d.) the following processes are suitable for the application of solar heat; some of which are very relevant for the metal processing sector:

- Pre-heating of raw materials
- Cleaning and washing
- Surface treatment
- Drying
- Boiler feed water
- Supply of hot water or steam

Due to the introduction of highly selective coatings, flat plate collectors can reach stagnation temperatures of more than 200°C in northern and central Europe. With these collectors, good efficiencies can be obtained up to the temperatures of 100°C, especially in southern European climates (Schweiger et al., 2000).

Another option for solar air heating systems are Transpired Solar Collectors (Figure 3.13), which are made of pre-finished perforated steel skins, which enhance the surface absorbance of solar energy. The steel skins are installed onto south-facing walls or roofs creating a cavity between the metal skin and the walls or roofs (SBED, 2017).

Figure 3.13. Schematic overview of a Transpired Solar Collector System (TATA Steel, 2017)



Negative air pressure created within the cavity by a ventilation fan draws ambient outside air through the micro perforations in the transpired solar collector's surface. This outside air is then heated as it passes through the perforations and collected within the cavity. Fresh heated air from the cavity is then fed directly into the building as ventilation air in industrial applications. A transpired solar collector can collect around 50% of the energy falling on its surface which equates to approximately 500 wp/m^2 of the collector's surface area and can deliver around 250 kWh/m^2 per year or up to 50% of space heating requirements depending on building configuration and usage (TATA Steel, 2017).

The installation of PV systems (Figure 3.14) usually follows the same rules and criteria as the solar collectors systems (please see above). The most popular technology is the so called Si-wafer based Photovoltaic that accounted for about 94% of the total production in 2016. The share of multi-crystalline technology is around 70%. The record lab cells have an efficiency of 26.7% for mono-crystalline and 21.9% for multi-crystalline silicon wafer-based technology. The Energy Payback Time of PV systems depends on the location of the installed systems: in Northern Europe around 2.5 years are needed to balance the input energy, while PV systems in the South equal their energy input after 1.5 years and less, depending on the technology as well. PV systems in southern Europe can have an energy payback time shorter than one year. Inverter efficiencies can reach up to 98% or more (Fraunhofer ISE, 2017).

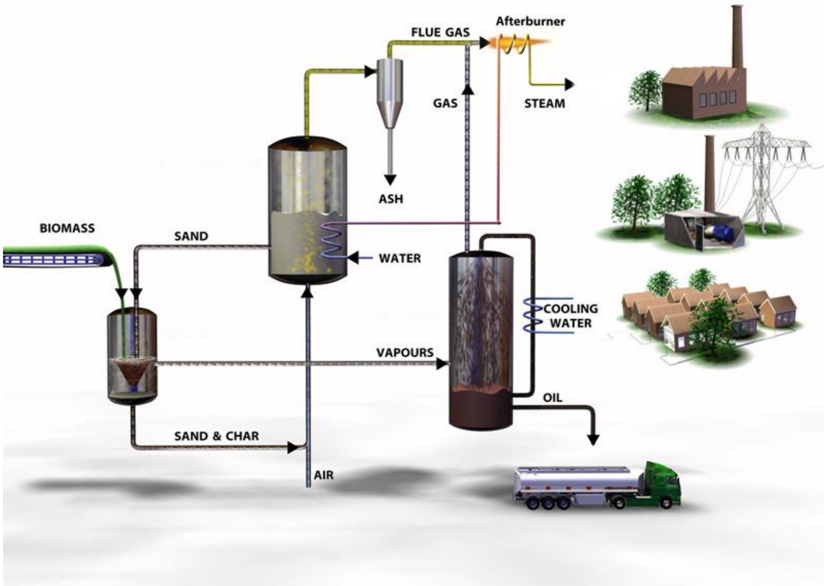
Figure 3.14. Rooftop PV at DENSO manufacturing plant, Barcelona

An additional renewable energy source that can be utilised is biomass (wood chips, pellets and manure as well as waste etc.). Biomass can be a feedstock for combined heat and power plants (CHP), whereby the pyrolysis and gasification technologies can convert the biomass feedstocks to heat, electricity and/or steam.

Biomass can provide high-temperature heat for process heat applications at different temperature levels are available on the market. The potential of biomass is large, especially in energy-intensive industries. Approximately three-quarters of the total renewable energy technology potential could come from biomass, which approximates to nearly tripling its current use by 2030. About 10 % of future biomass potential is used as feedstock and the remainder is shared between high-temperature applications (30 %) and other uses as fuel (60 %), (IRENA, 2014).

For instance, Figure 3.15) presents a fast pyrolysis process which produces oil that can be used for the vehicles (e.g. trucks or commercial vehicles), heat which is used for the heating of the offices and steam, which is used for on-site processes.

Figure 3.15. Fast pyrolysis process shifted towards the production of oil (BTG, no date)

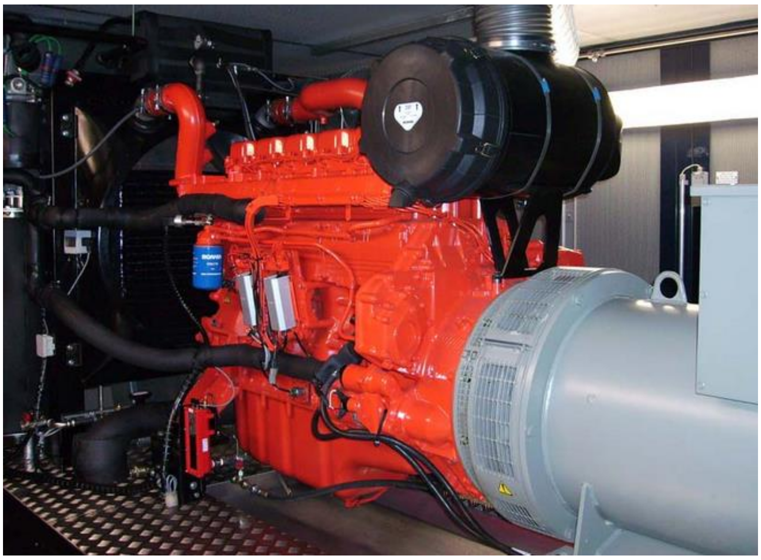


Case study 1: Grammer AG (Germany) and "Netzwerk-Energietechnik Amberg-Sulzbach", manufacturers of components for passenger car interior equipment, they operate a combined heat and power plant run by biofuel as well as woodchip boilers to meet the remaining needs. Fuel oil is only used to cover the peak load.

Heat suppliers and heat consumers on the factory premises (administration, warehouse, compressor room, metal processing, electroplating) are connected to each other via a heat line, the so-called "energy line". A central control system detects the heat demand as well as surpluses to help optimising plant efficiency and profitability. The combined heat and power unit is responsible for the basic load requirement of heat; the current is either used in the factory itself or fed into the public heating system. The middle load in the heat supply is taken over by two wood-chip boilers since this supply variant showed the best combination of economic performance, low CO_2 emissions and high flexibility.

The use of biofuels, wood chips and heating oil or the combined supply of electricity and heat offers the highest degree of flexibility and cost-protection. At the same time, about 2,000 tons of CO_2 per year (40%) are avoided compared to the old state (electricity supply from the grid and heat supply via oil boilers) (Energieatlas Bayern, no date).

Figure 3.16. The combined heat and power plant supplies the internal energy line



Case study 2, Volvo Group, automotive factory in Gent, Belgium. Investments were made in wind power to provide electricity. Around 50% of electricity 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 (Gaudillat et al., 2017). 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 (Gaudillat et al., 2017).

Case study 3: 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), (Gaudillat et al., 2017). 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) (Gaudillat et al., 2017).

Applicability

The BEMP is broadly applicable to all types of companies in this sector, including SMEs. However, there are geographical differences that affect the economic viability of this BEMP e.g. different feed in tariffs in case the electricity generated from renewables is provided to the grid.

The on-site generation of energy from renewable energy sources, especially applicable to PV (and more broadly to water and wind energy sources), has an important drawback, the low flexibility. The low flexibility, results in difficulties in the matching of the supply-demand and thus appropriate solutions, e.g. better management and forecasting of the generated energy, on the electricity network of the manufacturing company are essential.

Biomass can be used to produce process heat (via steam and direct heat) at varying temperatures, including high-temperatures applications above 400°C and is the only option to replace fossil fuel based feedstocks. Biomass can be easily integrated into the production process of different types of metal manufacturing with their large energy demands that require continuous access to energy and in most cases on-site land for storage (IRENA, 2014). Due to the good storability of wooden biomass, this does not represent a problem.

The use of heat from biomass in the various manufacturing processes seems challenging. In particular, the complexity of the manufacturing processes in combination with the need of high temperatures and incompatibility between heat demand and seasonality of renewable heat offer are important parameters that manufacturers need to deeply examine before making the choice of integrating heat from renewable sources in the manufacturing processes (Carbontrust, 2014).

The installation of solar systems in metal processing sites is related to more general heat supply for production halls or office rooms and to a certain extent also to warm water provision.

Energy storage technique strongly depends on specific needs and site specificities. Usually installations require a lot of available space for the placement of the batteries. Therefore, this technique may be more suitable for new built facilities where the space requirements have been taking into account during the design stage of the plant.

Economics

The economic viability and feasibility of the application of the measures of this BEMP vary between regions in terms of local legal regulations. For instance, the Renewable Energy Directive of the European Union defined individual national targets, taking into account the countries starting point and overall potential for renewables. These targets range from a low of 10% in Malta to a high of 49% in Sweden (European Commission, 2009). For regions with higher targets or higher overall potential, utilisation of renewable energy and/or implementation of a renewable energy system may be more accessible.

As regards the investment costs of rooftop PV systems a strong decrease could be observed between 1990 and 2013 where the annual grid-connected capacity in Germany was the highest. After 2013 the costs have remained more or less constant (Figure 3.17). Based on the fact that the energy prices grow fast, the installation of PV systems either connected to the grid or not, results in economic benefits for the manufacturing sites.

Figure 3.17. Investment for Small Rooftop PV Systems in Relation to Market Development and Subsidy Schemes in Germany (Fraunhofer, 2017)

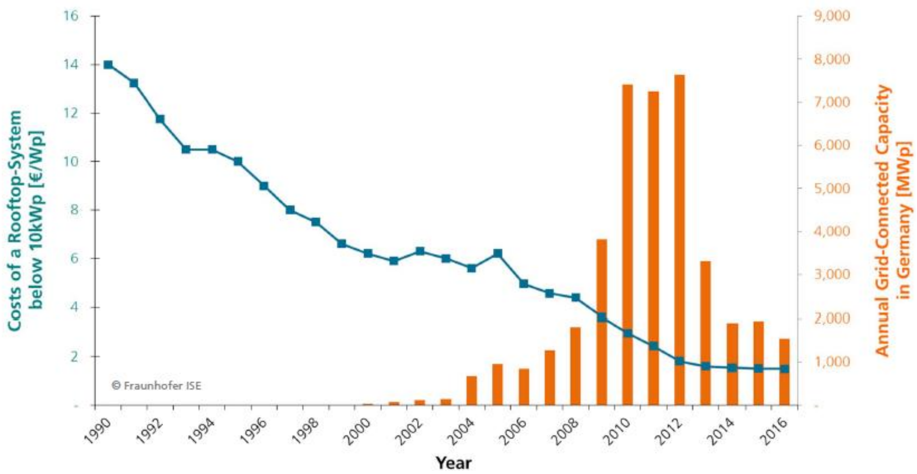
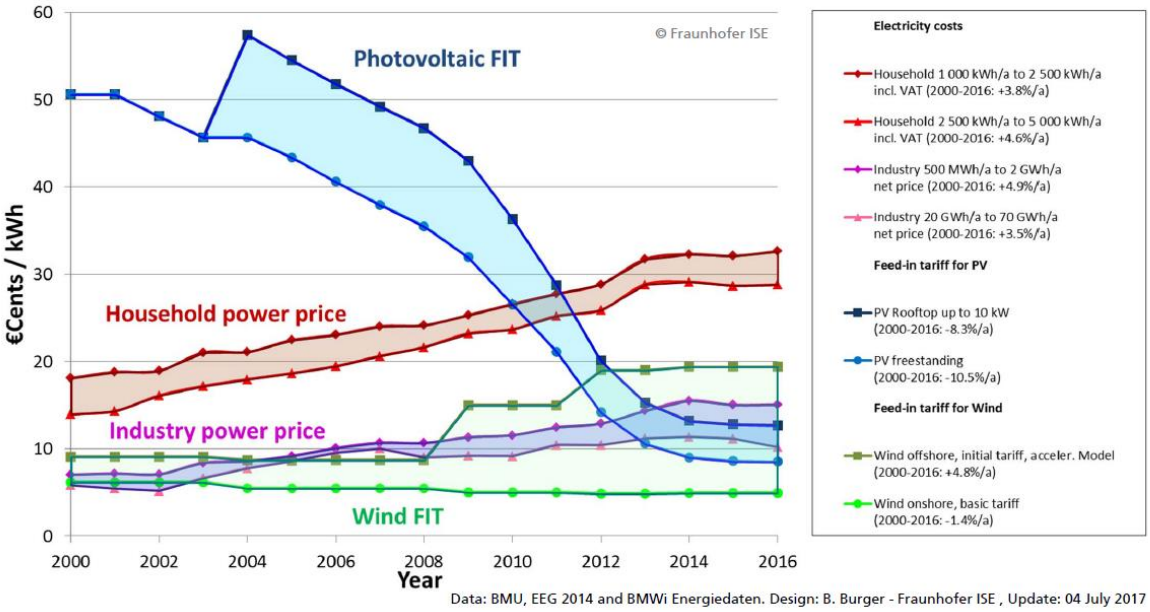


Figure 3.18. Electricity Costs and Feed-In Tariffs (FIT) in Germany



The different feed-in tariffs in each MS also impact the economic viability of the BEMP. In fact, the feed-in-tariffs have strongly decreased over the last 10 years for PVs and wind parks (Figure 3.18).

However, own energy (e.g. electricity) generation and self-consumption can result in reduced volatility of energy costs. Additionally, the green credentials from using renewable energy can be positive to retain and attract customers even in regions where otherwise purchasing green electricity would appear as just a cost.

The investment costs of a solar thermal system depend on the size of the plant. For solar thermal systems in the size of 10 m², costs may range from 600 to 1000 €/m². Likewise, for systems in the size of 10,000 m² costs may range from 200 to 400 €/m². These costs include the installation of all the necessary and auxiliary equipment e.g. heat exchanger, process integration, expansion vessel, stagnation cooler (EnPro, 2017).

The economics of electricity storage are difficult to evaluate because of several factors playing a role: the type of storage technology, the requirements of each application and the system in which the storage facility is located. The initial investment depends on the cost per unit of power (€/kW) and the cost per unit of energy capacity (€/kWh) both affecting the competitiveness of the system. Furthermore, the frequency of charging and discharging, also called cycling, is important mostly for the amortisation of capital costs and annual replacement costs, which have a significant impact on battery economics (SBC Energy Institute, 2013).

Driving force for implementation

Typically companies switch to energy generated from renewable energy sources with a view to substitute part of fossil fuels usage with renewable energy and possibly to reduce fuel and energy costs and associated CO2 emissions. Additionally, based on the fact that the energy market is subject to frequent fluctuations, companies switch to renewables in order to obtain independence from market turbulences.

Moreover, the improvement of the public image of a company can be an important driving force for implementation, a factor which is extremely relevant for B2C type of companies. However, for the fabricated metal products manufacturing sector the improvement of public image does not represent a main driving force for implementation of this BEMP due to the fact that the sector is dominated by B2B companies.

The choice of the type of the renewable technology is subject to the geographical location of the manufacturing site, the availability and proximity of each renewable energy source. Moreover, the climatic conditions in combination with the level of the support of the local governments determine the economic viability of the usage and the type of renewable energies e.g. solar energy is more suitable for climates with higher solar radiation values.

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3.6 Rainwater Collection

<table>
<tr><td colspan="6">SUMMARY OVERVIEW
BEMP is to reduce freshwater use at manufacturing sites by collecting and using rainwater in the various manufacturing or ancillary processes. Such a system collects rainwater from a catchment area (often the roof of the manufacturing plant or the parking space), has a conveyance system to collect it in a storage tank and a distribution system (pipes and pump) to bring it to the final use points.</td></tr>
<tr><td colspan="6">Relevant stages</td></tr>
<tr><td colspan="2">Cross cutting</td><td colspan="2">Optimisation of utilities</td><td colspan="2">Manufacturing</td></tr>
<tr><td colspan="6">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td></tr>
<tr><td colspan="6">Environmental performance indicators</td></tr>
<tr><td colspan="6">- Share of rainwater use on total water consumption (%)</td></tr>
<tr><td>Applicability</td><td colspan="5">The BEMP is broadly applicable to all types of companies in this sector, including SMEs. It is more suitable for new built or retrofitted plants and particularly to those plants where the collected rainwater can be used as process water. In case of retrofitting, the building characteristics may constitute a barrier to the implementation of the BEMP.
The geographical location highly influences the relevance of this BEMP (e.g. amount of precipitation, local water scarcity). In certain regions, the BEMP is compulsory by legislation for flood prevention and to reduce the use of ground water.</td></tr>
<tr><td>Benchmarks of excellence</td><td colspan="5">Rainwater is collected and used as process water in manufacturing and ancillary processes.</td></tr>
<tr><td>Related BEMPs</td><td colspan="5">N/A</td></tr>
</table>

Description

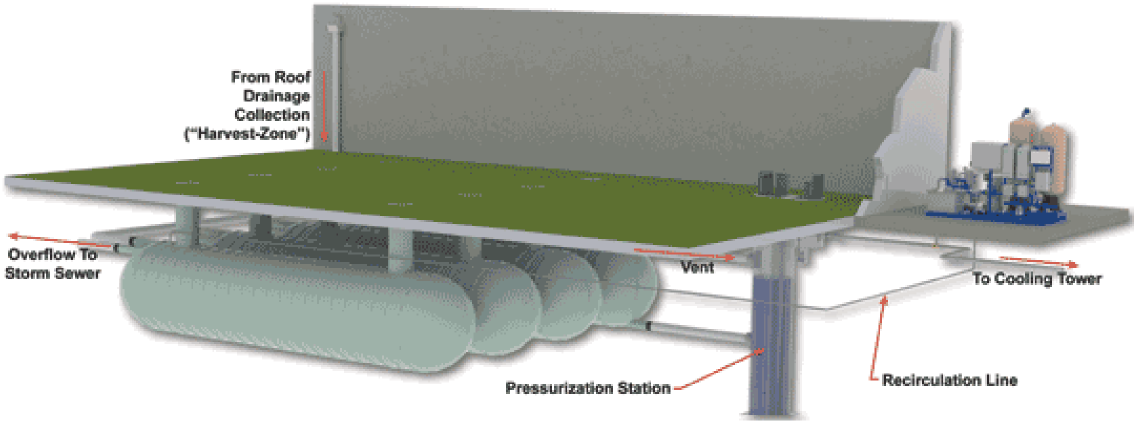
In Germany, 79% of the water consumed in the downstream sector in 2013, derived from natural freshwater sources, including groundwater, spring - and surface water as well as lateral storage water. The remaining 21% were taken from water providers and other companies, summing up to 12% of the total national water consumption. The metal fabricating sector was responsible for 10% of this share, mainly for cooling purposes as it was reported in UBA, (2017).

Water efficiency in manufacturing sites can be improved by different ways. Technologies such as the circulation of process and cooling water, if necessary with a partial flow treatment (membrane filtration), water-efficient rinsing systems (cascade rinsing) and the use of indirect cooling systems can be installed to reduce water consumption within manufacturing sites. Rainwater collection systems represent an important measure to make the manufacturing processes more sustainable and are broadly applicable for industrial uses.

Many metal machining processes and operations require large quantities of water, mainly for cooling and purging activities, which are often derived from freshwater sources. With the implementation of effective rainwater collection systems, a substitution could be achieved, at least to a certain extent (Hillenbrand et al., 2008). These systems typically consist of a set of gutters, duct pipes and tubes, placed on the roof of the manufacturing plant, a (or a series of) special tank(s), underground or on the ground and a pressurization tank. Dedicated pumps are employed to move the water to the final consumption points within the manufacturing plants (Figure 3.19).

The special tank(s) where the rainwater is collected is equipped with filters and pumps which ensure that the harvested water is not contaminated and can be used safely in the manufacturing processes and operations.

Figure 3.19. Industrial rainwater collection system (Waterworld, no date)



The capacity of the rainwater collection system needs to be carefully calculated. Also, the auxiliary equipment e.g. pipes, tanks and valves need to be sized precisely in order to avoid over dimensioning and thus inefficient operation.

The first step is to consult (local) meteorological data from the region e.g. precipitation levels in a monthly or weekly basis. The second step is to compare these data against the actual needs of water of the manufacturing site, both for manufacturing and ancillary processes. The assessment of these data gives a precise estimation of the capacity of the system and results in its optimum sizing.

Achieved environmental benefits

The application of rainwater collection systems can lead to a significant reduction of fresh water consumption within the manufacturing site.

In some industrial sectors such as the steel industry, water is usually treated and reused several times. According to Worldsteel Association (2015), in steel production processes around 90% of used water is returned to the plant for reuse in the various manufacturing processes and operations. Moreover, rainwater collection system, when installed properly, can improve the management of storm-water runoff of the manufacturing site in the case of intensive precipitation events because the system can function as a buffer, preventing erosion and flooding.

Appropriate environmental indicators

The indicator of this BEMP measures essentially the share of rainwater used out of the total water consumption in the manufacturing processes and operations:

- Share of rainwater consumption on total water consumption [%]

Cross-media effects

If the collected water is not preserved carefully and becomes contaminated then health problems can occur, especially when the water is used without pre-treatment. In addition, in water-scarce areas, if rainwater collection systems are too large in relation to their catchment area, imbalances in the water cycle can occur, leading to shortages for the local environment.

Operational data

Industrial rainwater collection systems are available in several sizes and formats and are offered from a broad group of suppliers.

Prior to its installation, the first step is to retrieve data about the water rainfall (monthly or weekly) at local level (

Table 3.15).

Table 3.15. Example from the monthly rainfall data for the calculation of the capacity of the rainwater collection system (Chacire et al., 2016)

Year	**2013**	**2014**	**2015**
Month	Average rainfall (mm)		
January	-	-	0.60
February	-	-	-
March	-	-	5.28
April	-	-	5.76
May	-	3.1	16.1
June	24.38	13.6	30.19
July	20.83	26.6	2.71
August	11.24	14.6	16.39
September	6.95	14.39	15.91
October	29.85	3.43	10.9
November	-	-	-

The second step is the calculation of the catchment area; in particular, the rooftop area of all buildings of the manufacturing site needs to be considered in the calculations. Then the number of drains, along with their technical characteristics such as drain spacing and diameter of drains are designated accordingly (Table 3.16).

Table 3.16. Example for the calculation of the number of drains against the rooftop area of all buildings of a manufacturing facility (Cachire et al., 2016)

Building's number	Roof top area (m2)	Number of drains	Drain spacing (m)	Diameter of drains (mm)
1	7,910	37	8	150
2	11,850	30	12	150
3	4,969	20	8	150
4	4,424	8	6	150
5	5,086	34	8	150
6	4,134	20	8	150
7	7,146	26	12	150
8	7,542	24	12	150

Case Study: BMT Group[47]

The BMT Group manufactures precision gears, transmissions and actuators. The company has installed rainwater harvesting systems in various manufacturing sites across Europe. with the aim to reduce the needs for fresh water. For instance, in their manufacturing site in Croatia a lagoon has been created to collect rainwaters, which are used for sanitary needs and set up of emulsions. In another manufacturing site in Iasi, Romania, BMT Group has installed an underground tank for harvesting of rainwaters, which are reused in the production process (BMT Group, 2015).

Applicability

This BEMP is broadly applicable to the companies from the sector regardless their size. In general, the rainwater collection systems are more effective where the quality of the collected water is high, so that the need for pre-treatment is minimised (WRAP, 2010).

The installation of rainwater collection systems is more applicable in new-built plants. In the case of retrofitting the characteristics of the buildings (e.g. shape, architecture) can limit the applicability of the BEMP.

The climate conditions of the geographic location of the manufacturing site can constitute a major limitation for the applicability of this BEMP. For example, the amount and the frequency of the precipitations may decrease the relevance of the implementation of the BEMP due to disproportionate cost for the installation of distant storage tanks. Similarly, in some regions with cold and wet climates this BEMP is compulsory by legislation.

On the contrary, in regions with hot and dry climate conditions, the collection of rainwater can be an important driver to reduce fresh water consumption. In this case, it has to be evaluated whether rainwater collection is applicable due to low precipitation rates.

[47] In BMT Aerospace site in Oostkamp (BE), the installation of a rainwater resulted in the increase of the reuse of rainwater from around 2 m^3/person in 2014 to around 7 m^3/person in 2015. Similarly, they have also increased their re-used rainwaters at their subdivision, the OMCO Group, in Aalter (BE) from 2 m^3/person in 2014 to 3 m^3/person in 2015.

Economics

The cost of installing rainwater collection system in manufacturing sites depends generally on the size of the catchment area (surface) and complexity of the system e.g. collected water used in the production or ancillary processes. Typically the capacity of the system in relation to the amount of precipitations of the location of the manufacturing site gives an estimation of the investment needed and on the payback time.

However, the price of the water (fresh water, surface water, well water) in the location of the manufacturing site will define how much beneficial for the manufacturer is the implementation of this BEMP.

Driving force for implementation

The reduction of fresh water in the manufacturing operations and processes is the main driving force for implementation of this BEMP.

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BMT Group

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4 Manufacturing processes

The BEMPs of this chapter address the core manufacturing activities and processes of the companies from the sector. These BEMPs focus on the improvement of the environmental performance of the manufacturing processes that companies carry out and provide guidance on how to reduce the direct and indirect environmental impacts.

Table 4.1 lists the BEMPs from the manufacturing chapter against the related direct environmental aspects, pressures and the relevant BREFs.

Table 4.1. Most relevant direct environmental aspects for the fabricated metal products manufacturing companies how these are addressed in the manufacturing processes – management practices chapter

BEMPs	Most relevant direct environmental aspects	Related main environmental pressures	Relevant BREFs
4.1 Selection of Metal Working Fluids 4.2 Minimisation of lubricoolant consumption in metal processing 4.3 Incremental sheet metal forming as alternative for mould making 4.4 Reduction of standby energy of metal working machines 4.5 Maintaining material value for metal residues 4.6 Multi-directional forging 4.7 Hybrid machining as a method to reduce energy use 4.8 Use of predictive control for paint booth HVAC management	Industrial processes, manufacturing operations	Energy Waste Water Emissions to air Emission to water Noise, odour, vibration etc. Waste: Hazardous, non-hazardous	STS FMP SF

4.1 Selection of resource-efficient Metal Working Fluids

SUMMARY OVERVIEW

BEMP is to select resource efficient metal working fluids by:

- carrying out systematic science-based in-depth assessments of available metal working fluids, according to a broad set of criteria, including both environmental and economic aspects, with consideration of the entire life cycle of the fluids and of the manufactured products.
- looking for available metal working fluids that can provide different functions (e.g. lubrication, chip removal, cleaning) at the same time, or can be used more than once after appropriate recovery and/or reformulation.

BEMP is also to evaluate and control the performance of the selected metal working fluids during or after their application by means of a monitoring system.

Relevant stages

Cross-cutting	Optimisation of utilities	**Manufacturing**

Main environmental benefits

Resource efficiency	**Water**	**Waste**	**Emissions to air**	**Energy and climate change**	Biodiversity

Environmental performance indicators

- Total amount of metal working fluids purchased per year (kg (or l)/year)

- Total amount of recovered metal working fluids per year (kg (or l)/year)

- Number of different metal working fluids used in the company (total number of metal working fluids)

- Consumption of metal working fluids per manufactured product (kg (or l)/ kg finished product or manufactured part)

Applicability	This BEMP is applicable to all types of companies in this sector, including SMEs. However, the lack of in-house technical knowledge can constitute a barrier, especially in SMEs.
Benchmarks of excellence	The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement in, at least, the following indicators: - energy use per manufactured product - resource efficiency - consumption of metal working fluids[48] per manufactured product
Related BEMPs	2.4

[48] N.B. Metal working fluids consist of oils, oil-water emulsions, pastes and gases. Therefore, it can be of either solid, liquid or gas form, influencing thus the type and the equipment needed for their application and eventually the metrics used in the benchmark to monitor improvement in the environmental performance of this aspect.

Description

Metal Working Fluids (MWFs) are used in large volumes worldwide and it was reported that their consumption in the EU and Russia was approximately 610.000 t in 2010 (Benedicto et al., 2017).

The selection of the MWFs is a complex issue and it is influenced by many operational parameters. Manufacturers prior to selecting MWFs shall carefully assess the different MWFs against environmental and economic criteria, considering the entire life cycle of the products and the MWFs. Given the complexity of this action, the BEMP is structured as follows in order to facilitate the manufacturers to select the most suitable MWFs:

1. The different functions of MWFs
2. Physical and chemical diversity of MWFs
3. Resource-efficiency issues related to MWF
4. Ways where the use of right MWFs can improve resource efficiency
5. Evaluate and control the performance of the MWFs

When MWFs are properly selected, the overall environmental performance of the manufacturing site is improved. However, manufacturers prior to selecting MWFs shall carefully check and review the technical specifications of all the manufactured products (e.g. type of materials processed) and the requirements of the manufacturing operations carried out.

MWFs have to be evaluated along their entire value chain from their production until the end-of-life, in accordance to their chemical and physical basis as well as their field of application and disposal at the end of their service life. Manufacturers usually select MWFs in close cooperation with MWF suppliers who are not interested to deal with already running procedures of the manufacturers.

1. The different functions of MWF

MWFs are typically used to ensure the quality of the machined tool and part, reduce tool wear and overall to improve process productivity. MWFs affect heat generation in metalworking processes, through which thermal damages can be avoided and the tool wear can be reduced. They are also used for cleaning of the machined parts (e.g. removal of the swarfs), cooling and lubricating the machining processes. They contribute to the setting of operational parameters such as cutting speed, depth of cut and feed rate. Furthermore MWFs play a role in chip transportation out of the working zone and in avoiding dusts (Brinksmeier et al., 2015; Benedicto et al., 2017; Astakhov and Joksch 2012).

The choice of the applied MWFs is greatly linked to the type of machining process used, the materials processed and tools used. They are mostly used in forming, cutting and grinding processes. Changes in the chemical composition of the MWFs and/or in the tools and materials processed can influence the performance of the manufacturing processes considerably (Brinksmeier et al., 2015).

2. Physical and chemical diversity of MWF

MWFs[49] consist of straight oils and water-soluble oils and they can be found in solid, liquid or gas form[50]. The water-soluble oils are further classified into soluble oils, semisynthetic and synthetic, based on their oil content. The latter 3 types of MWFs are generally sold in form of concentrates that have to be diluted with water at the moment

[49] Manufacturers can also consider the selection of MWFs compliant with the EU Ecolabel lubricants; Commission Decision (EU) 2018/1702, available online at: http://ec.europa.eu/environment/ecolabel/products-groups-and-criteria.html

[50] Their form influences the type of the equipment needed for their application (Brinksmeier et al., 2015).

of application. The produced solution (obtained MWF) can be prepared carefully to meet multipurpose functions.

The first step in the selection of the proper fluid usually involves a choice between using a water based MWF or a straight oil. This selection depends on the lubrication specifications and the severity/intensity of the machining operations (

Table 4.3). Also, the safety and environmental restrictions and measures in place are needed to be taken into consideration. Table 4.3 illustrates the advantages and disadvantages of the 4 basic types of MWFs (Byers, 2009).

Table 4.2. Fluids and possible applications (adapted from Byers, 2009)

Severity of operations	Processes	Synthetics	Semi-Synthetics	Soluble Oil
Light	Milling, surface-, double disk- and rotary grinding	Rust inhibitors and cleaning inhibitors only. No lubricants	Low oil content (5-10%) plus rust inhibitors	
Moderate	turning; internal-, centre type- and centreless grinding	Some polymeric lubricants	High oil content (20-30%)	High oil +/- esters and fats
Heavy duty	Drilling, sawing and cut-tapping; creep feed- as well as form-, threat- and flute grinding	High level polymeric lubricants plus phosphate ester	High oil plus EP lubricants	High oil plus EP lubricants

Table 4.3. Advantages and disadvantages of the four basic MWF groups (Byers, 2009)

STRAIGHT OILS	SOLUBLE OILS	SEMISYNTHETICS	SYNTHETICS
ADVANTAGES			
Excellent lubricity	Excellent physical lubricity	Good heat reduction	Very clean
Excellent rust control	Some heat reduction	Physical lubricity	Excellent heat reduction
Long sump life	Easy to manage	Clean	Unaffected by hard water
Easy to manage		Good rust control	Low foam
			Rejects leak oil
			Transparent mix
DISADVANTAGES			
Expensive fill-up	Heavy oily residues	May foam	Poor physical lubricity
Excess heat generation	Affected by hard water	Affected by hard water	No oily protective films
Fire hazard	Blue haze, mist, smoke		
Messy, slippery hazard			
High oil mist in air			

3. Resource-efficiency issues related to MWF

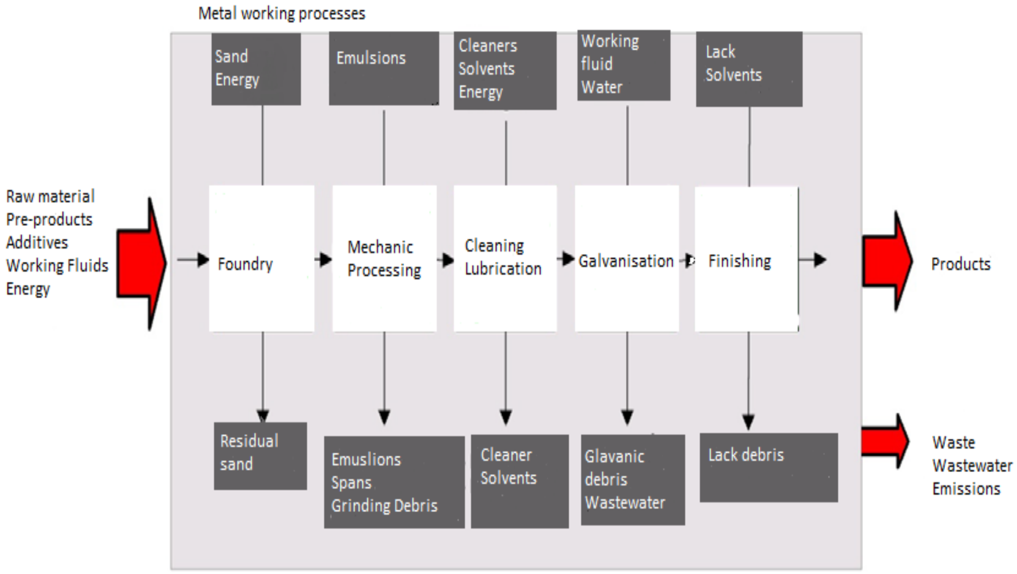
Once the severity and intensity of the manufacturing operations is defined, a number of other factors have to be considered for the choice of the right MWFs (Byers, 2009 and OECD, 2011):

- Metals involved both as material to be processed and the constituent of tools
- Chemical restrictions inside the plant or by law
- Water hardness

- Type of MWF supply (from individual tanks or a large central system)
- Presence of metal chip removing system or accumulation in machine sump
- Presence of oil collecting system from the sump
- Type of fluid disposal system, recycling structures etc.
- Multipurpose applications, e.g. by offering different functions at the same time
- Operator security issues such as contact time with the fluid, dust formation etc.
- Container residue released to water, or sent for incineration or landfill
- Drag-out losses released to water
- Filter media and other recycling waste released to uncertain media
- Spent MWFs released to water

All these aspects have to be considered for each single metal working process illustrated in Figure 4.1.

Figure 4.1. Metal working processes (adapted from ABAG-itm, Pforzheim)



4. Ways where the use of right MWFs can improve resource efficiency

The right selection of MWFs (as it was stated in the previous steps) leads to significant reduction of hazardous chemicals, longer life of tools and may also lead to simplifications of MWF compositions.

Another possibility to reduce the releases to the environment is to make use of multipurpose MWFs or MWFs with multiple functions. These substances are not linked to a specific purpose and can therefore be used for several applications and processes. In combination with recovery schemes and effective filter systems the lifetime of a MWF can be prolonged significantly, which reduces the environmental impact due to lower raw material requirements as well as decreased waste generation. This can be achieved through the avoidance of mixing different substances, which is further linked to improved working security.

Multipurpose MWFs can either be used after their recovery and reformulation. In fact, used MWFs have to be separated from aerosols, contaminations and metal residues in order to make them reusable51.

In the case a company can make use of multi-purpose MWFs, overall productivity and efficiency of the tool processed and the component manufactured are considerably improved (see further information in Achieved environmental benefits section).

5 Evaluate and control the performance of the MWFs

The implementation of a monitoring system for the effective management of the MWFs is also essential. The establishment of such a monitoring system contributes to reducing waste by keeping machines clean and decreasing down times and tool wear (University of Northern Iowa, 2003).

Certain physical and chemical parameters of the MWFs are typically monitored in order to understand their condition. These are: i. pH value, ii. nitrate/nitrite concentration, iii. amount of bacteria, iv. impurity content and v. content of foreign oils. If one or more of the above mentioned parameters monitored are exceeded then the MWF is considered degraded. Processing of materials with degraded MWFs leads to quicker wear of the tool and/or even damage to the production lines (including health aspects e.g. skin problems). A degraded MWF in a machine needs to be replaced. Also, the system needs to be cleaned and a new liquid has to be added. Therefore, the stability of the machining process it is ensured by continuously monitoring and maintaining the state of the MWFs in the machines in the working range, as they are prescribed by the manufacturer and suppliers of the MWFs (Jurina and Peterka, 2018).

Real-time monitoring systems are being applied by various manufacturers. These systems allow the monitoring of multiple variables (e.g. the abovementioned MWFs parameters) at the same time. The obtained data are then evaluated and the control mechanism, when necessary, takes measures to modify the parameters such as adding additives to correct/adjust the properties of the MWFs. Additionally, these systems can collect data on the chemical basis of the MWFs, emissions from production and disposal, expected tool wear etc. The collected information and data are assessed and is used to give feedback about the potential reusability of the tools and MWFs (Ministry of Environment, Climate and Energy Baden Württemberg, 2015).

Thanks to the features of these systems, the machining operations are carried out within the recommended working ranges and thus the maximum environmental benefits are achieved.

Achieved environmental benefits

The environmental benefits of selecting the most appropriate working fluid for metal processing are strongly connected to improved efficiencies. Different kinds of MWFs can also have diverse environmental benefits related to their chemical basis, field of application and the implemented technology. In addition, a reduction of the number of different substances (e.g. through application of multipurpose MWFs) can limit the risk of contaminations and cross media effects due to incomplete cleaning processes or mixing of substances in the drainage.

Water based MWFs compared to oil based MWFs are more environmentally friendly due to decreased emissions during production and less hazardous waste after their application, but have much higher water and land use demand (VDI, 2017). Generally, achieved environmental benefits through the selection of the right MWFs can be:

[51] More information about the recovery of MWFs can be found in the BEMP 4.5.

- Overall lower consumption of MWF leading to less raw material consumption and reduced energy consumption for production and disposal of MWF
- Reduced number of different types of MWFs
- Reduction of greenhouse gas emissions resulting from the avoided production of MWFs and their disposal
- Reduced downtimes due to potential avoided cleaning phases and MWF replacement between different processes leading to lower overall GHG emissions
- Increased productivity and lower possibility of failure
- Reduced tool wear leading to extended tool life and less machine downtime that brings to further energy savings

Appropriate environmental performance indicators

Appropriate environmental indicators for the selection of MWFs are:

- Total amount of metal working fluids purchased per year (kg (or l)/year)
- Total amount of recovered metal working fluids per year (kg (or l)/year)
- Number of different metal working fluids used in the company (total number of metal working fluids)
- Consumption of MWFs per manufactured product (kg (or l)/ kg finished product or manufactured part)

N.B. The form of the applied MWFs e.g. solid, liquid influences the metrics used in the indicators. Therefore, companies can choose the metrics that are suitable for their operations.

Cross-media effects

The introduction of criteria for the selection of the most appropriate MWF for the single processes has generally no cross-media effects.

However, for a comprehensive evaluation not only the MWF life cycle but also the whole tribological system needs to be considered, including tools, peripheral components like filter systems and their respective energy demands. This assessment may be quite time consuming and special expertise will be required to gain the highest possible output.

In the case of multipurpose MWFs, the work load for operators can increase and higher expertise is required in order to achieve the highest output (i.e. due to application of different concentrations of a MWF for different purposes). This can reduce overall efficiencies and lead to contaminations in the case of wrong handling. However, this can be prevented by the implementation of trainings and continued education.

Operational data

Case study: Standardised use of different oils – Metaplast

The company Metaplast, based in Hungary, has standardised the use of different oils and emulsions by selecting the optimal chemicals in direct and non-direct production areas, which resulted in considerable savings in logistics and administration efforts as well as costs.

Metaplast faced the situation of applying 17 different oils, four emulsions and three cleaners, which were incompatible with each other. This led to chemical interactions, resulting in a bad air quality in the working area, possibly leading to long term health and safety problems. To have certainty, the company conducted air quality analyses, providing undoubtable results.

After a standardisation of chemicals by the Health and Safety supervisor of the company, a significant reduction of chemicals in stock could be achieved. This also resulted in increased process efficiencies and a decrease in unpleasant chemical interactions due to avoided application of incompatible as well as too old lubricants.

An important factor to be taken into consideration was the careful planning of the preventive maintenance and to convince employees that new types of oil or other lubricants can bring the same or even better results.

Case study: Application of multipurpose MWF after selection process

A major global manufacturing subcontractor of innovative braking systems for the automotive industry applied a new formulated MWF that includes a compatible, two-part coolant and cleaner that can be applied for more than one specific operation. The two-component product involves an alkaline and oil phase and is typically mixed into water to generate emulsions for machining and grinding operations. When mixed solely with water, the alkaline phase can additionally be used as process cleaner. In this case, the fluid can be repurposed in the cutting fluid tanks for top-ups and can therefore be used twice. This leads to a reduction of waste generation of up to 90%, bringing to improvements both in environmental and economic efficiency, especially for customers with CNC units connected to large centralized systems.

In addition to reduced waste water quantities, the following positive effects can occur:

- Water consumption is minimized because the cleaners are reused for making up the top up emulsions
- Capital investments in wastewater treatment equipment can be reduced or eliminated
- Energy and wastewater treatment costs are reduced because significantly lower quantities need to be treated

The concept is based on the versatility of its chemical components and a new process chain. Through the application of a two-component fluid many dedicated fluids for different machining processes can be replaced. To meet a wide variety of coolant and cleaner needs, the MWF is formulated in different solution ratios of the alkaline and oil phases mixed into water to prepare emulsions.

For operations requiring higher levels of lubrication, the "oil phase" is used at a higher ratio to provide a more robust, high-performance micro-emulsion. The high versatility however allows the MWF to be used as a process cleaner as well. When the cleaner solution becomes saturated, instead of being disposed of, it is added to the coolant tank to aid with volume control ("top-up") (Quaker, 2014).

Applicability

This BEMP is broadly applicable to all types of companies in the sector, including SMEs. However, assessments for selecting the right MWF may be rather time consuming, and expert knowledge / technical capacity is required due to the complexity of many MWFs and their functioning. These may constitute a barrier on its applicability particularly for SMEs. However, selecting the most appropriate MWF is relevant for every type of fabricated metal products manufacturing company for several reasons. The environmental performance can be improved due to increased efficiencies of metal shaping processes consequently leading to lower energy use, higher material efficiency and reduced waste production. Furthermore, MWFs strongly affect machining processes and are responsible for a relevant share of operational costs (8-16%).

The application of MWFs which cover multiple purposes or functions is expected to gain more importance. Based on the understanding, which components are definitely required in a MWF to fulfil a specific function, the production of simplified MWFs can be possible. Furthermore, knowledge-based combination of suitable substances should additionally allow for using single MWFs for different applications. Tools such as the life cycle assessment will reveal further potentials as regards the substitution of mineral oil based substances by renewable alternatives (Brinksmeier et al., 2015).

Economics

The economic aspect of the selection of metal working fluids is difficult to assess because it strongly depends on the single companies and their initial situation. Considering the case of coolants, they usually have a small share on the total costs but can influence many secondary aspects such as tool wear, energy use, output quality and overall productivity that are relevant for the overall revenue.

In the case of externally supported selection process, expenses for hiring experts shall be included. However, also if internal staff is instructed with the optimisation of MWF management, working power is shifted, which is to be considered. Depending on the amount of MWFs applied in the company and on the currently performance of the system, such a selection process is economically beneficial.

In general, the technological potential of well adapted and highly efficient MWFs may compensate the comparatively high costs for selection processes. Life Cycle Costing (LCC) is construed to consider also follow-up costs and to provide information about the entire product life cycle, wherefore it can help to justify so called spend-to-safe decisions (Brinksmeier et al., 2015).

The main positive effects from applying the right MWF in relation to the costs are:

- Increased overall process efficiency
- Reduced energy consumption
- Less expenses for MWFs
- Prolonged tool life due to reduced wear
- Reduced waste amounts

A case study elaborated by Winter et al. (2014) investigated the influence of different metal working fluids (MWFs) on process energy demand and costs. The study showed that the application of different mineral oil based cutting fluids results in varying process energy demands and costs. Furthermore, it was shown that the energy costs (73%) are responsible for a much bigger share of process costs than the MWF costs (27%). Taking in consideration shorter standby times in the case of multipurpose MWFs, the energy costs can be reduced wherefore an overall increase in productivity can be achieved. In that way, higher costs for multipurpose MWFs can be compensated (Winter et al., 2014).

Nevertheless, these aspects are difficult to quantify precisely since they are interconnected and further depending on other factors such as employee performance and quality issues. Time consuming selection processes are most suitable for companies with high MWF consumptions and especially in cases when contracts with substance suppliers have been untouched for several years.

Driving force for implementation

The major driving forces for the implementation of MWF selection are:

- Process efficiency improvements including lower overall MWF consumption, reduced tool wear, less energy use and smaller amounts of waste

- Economic reasons
- More secure working environment for operators (e.g. in case of multipurpose MWFs handling only a few substances that combine several functions instead of dealing with a large variety of MWFs with different characteristics and handling instructions)

Reference organisations

Metaplast Gear Technology (Hungary) applied a selection process for MWFs due to the occurrence of air emissions, leading to a reduction of different substances and improved air quality for employees (Metaplast, 2017).

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4.2 Minimisation of lubricoolant consumption in metal processing

<table>
<tr><td colspan="7">SUMMARY OVERVIEW
BEMP is to minimise the use of lubricoolants in metal processing and shaping operations. This can be achieved by applying techniques such as cryogenic cooling or high pressure lubricoolant supply. These techniques result in reduced waste generation, higher overall process efficiencies and consequently lower energy use as well as extended tool service life.</td></tr>
<tr><td colspan="7">Relevant stages</td></tr>
<tr><td colspan="2">Cross-cutting</td><td colspan="3">Optimisation of utilities</td><td colspan="2">Manufacturing</td></tr>
<tr><td colspan="7">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td><td>Hazardous substances</td></tr>
<tr><td colspan="7">Environmental performance indicators</td></tr>
<tr><td colspan="7">- Consumption of lubricoolants per processed part (l/part)</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="5">This BEMP is broadly applicable to all types of companies in this sector, including SMEs. Due to its energy intensity, it is more suitable for small series or prototypes and for new or renewed installations rather than retrofitting on an ongoing process.
However, the energy intensity is a parameter that needs to be carefully examined on a case-by-case basis. This, in combination with the lack of in-house technical knowledge and expertise may constitute a significant barrier for the application of this BEMP.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="5">The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement in, at least, the following indicators:
- energy use per manufactured product
- resources efficiency
- consumption of metal working fluids[52] per manufactured product</td></tr>
<tr><td colspan="2">Related BEMPs</td><td colspan="5">BEMPs 2.4, 2.7, 4.1</td></tr>
</table>

Description

Lubricoolants are broadly applied in the metalworking industry to cool and lubricate the cutting site in several processes and to facilitate chip removal. They influence heat generation by reducing the friction between tool and workpiece, so that thermal damages of the workpiece are avoided and tool wear is decreased.

[52] N.B. Metal working fluids consist of oils, oil-water emulsions, pastes and gases. Therefore, it can be of either solid, liquid or gas form, influencing thus the type and the equipment needed for their application and eventually the metrics used in the benchmark to monitor improvement in the environmental performance of this aspect.

The use of lubricoolant is essential especially when machining of high alloyed steels or heat resistant materials, such as titanium- and nickel-based alloys. For this reason, it is necessary to use lubricoolants as effectively as possible in order to optimise productivity and process stability (Klocke et al., 2013).

Every machining operation has specific requirements for cooling versus lubrication. By modifying the mix ration or concentration of a water based solution, it is possible to alter the balance of cooling and lubrication.

As a general rule of thumb, fluids with more water content improves the cooling; on the contrary, when the oil content is high the lubrication properties increase. However, each process needs to be examined on a case-by-case basis to determine proper concentration requirements and determine whether lubrication or cooling is required. This BEMP deals with the application techniques of lubricoolants.

Application of lubricoolants

There have been developed techniques for the effective management and application of lubricoolants that reduce the environmental threats and improve the resource efficiency of the machining processes. The first step is to understand the specific technical requirements of each process and specifically whether application of lubricoolants is required (e.g. dry cutting process).

In case the machining must be carried out under wet conditions inevitably then the application of lubricoolants needs to be carefully designed. The most promising techniques for the application of lubricoolants are the cryogenic cooling and the high pressure lubricoolant supply. These two techniques are described in the next paragraphs.

<u>Cryogenic cooling</u>

Cryogenic cooling is the process of implementing and delivering non-oil-based cooling media such as liquid nitrogen (LN2), carbon dioxide (CO2), liquid hydrogen (LH2), liquid oxygen (LO2) or dry ice/CO2 snow to the cutting zone (Figure 4.2). When cryogenic cooling is applied, the cutting temperature is reduced, which enables the application of higher (more complex) cutting parameters (e.g. processing of parts with complex geometries) (Klocke et al., 2013).

LN2 and dry ice are frequently used for cooling during cutting processes due to their good availability and relatively safe handling. The advantages of cryogenic cooling derive from the lower cutting temperatures compared to conventional methods. This leads to significantly lower levels of tool wear, improved cutting performance and higher overall process quality (WZL, 2017).

The main benefits of using cryogenic cooling media compared to metal working fluids (MWFs) are the clean, colourless, tasteless, non-combustible and non-corrosive characteristics. The application of cryogenic cooling media into the cutting zone does not leave residues or contamination on the tools and machining zone due to the fact that cooling media are evaporated. Therefore, disposal of lubricoolants and/or cleaning of tools and machines are avoided.

Figure 4.2. Cryogenic cooling for a drilling process (Toolingandproduction, 2017)

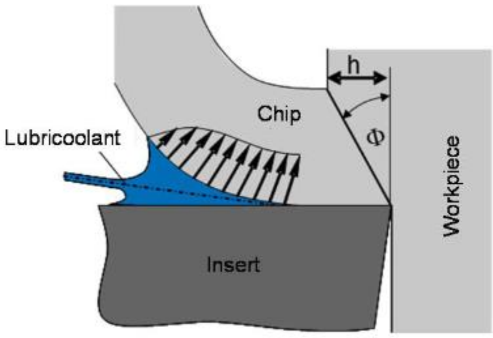
High-pressure lubricoolant supply

For difficult-to-process parts, the conventional supply of the lubricoolant is not so effective, since the high temperatures at the cutting zone cause the lubricoolant to vaporise. The high-pressure lubricoolant supply does not contribute to vaporising the lubricoolant but enables it to get closer to the cutting edge. Therefore, it results in enhanced cooling of the tool (Klocke et al., 2011; Klocke et al., 2013). This contributes to longer tool life, when compared to conventional supply (flood cooling technique), especially when processing e.g. milling, drilling titanium-based or nickel-based alloys. The tool wear reduction is a consequence of lower process temperatures; the chip breakage benefits from higher mechanical forces due to the lubricoolant high-pressure supply together with stronger cooling that reduces the material strength because of low temperatures (Klocke et al., 2015).

High-pressure lubricoolant supply makes use of pumps to create increased volume flows generating much higher pressures compared to conventional lubricoolant supply techniques. One or more nozzles near the cutting zone mounted on the tool holder itself further improve cutting results).

Manufacturers typically combine the pressure and the volume flow of the lubricoolant accordingly, in coordination with the cutting parameters and the tool design in order to enable a higher productivity rate and assure profitability (Klocke et al., 2015). It is usually used for the processing of materials with high cutting speeds/velocities.

Figure 4.3. High pressure jet assisted lubricoolant supply (Klocke et al., 2015)



This technique results in the increased cooling of the cutting zone. The working (cutting) fluid penetrates between the bottom of the chip and the rake face of the tool. Therefore, the friction is reduced significantly when compared to other conventional cooling techniques for machining processes.

Achieved environmental benefits

The major environmental benefits for the cryogenic cooling and the high pressure jet assisted lubricoolant supply are (Dahlman, 2002; Duflou et al., 2012; Klocke et al., 2013; Dobbeler and Klocke, 2017):

- Decreased raw material consumption (i.e. water, chemicals, solvents etc.)
- Reduced waste amounts from operations where lubricoolants are used
- Significant prolongation of tool life because of reduced tool wear and connected lower material input
- Reduced water consumption and total energy use compared to conventional flooding process because of shorter process times and substitution of water as coolant
- Reduced cutting temperature
- Improved chip control (but strongly dependent on the pressure and flowrate of the high pressure supplier)
- Optimised operation of the production lines, while is linked directly to higher overall process efficiencies and consequently lower energy use (especially for the cryogenic technique)

In the case of cryogenic machining the lower temperatures result in increased hardness and toughness of the cutting tool, which in turn allows higher material removal rates. The consequences are an increase in productivity and consecutively lower total energy use. Moreover, the use of LN2 as a coolant in complex grinding operations led to the avoidance of thermal damages, leading to reduced material wastage.

In respect to the high-pressure jet lubricoolant supply and compared to conventional flooding, unnecessary heating of the cooling lubricant and increased foam production can be avoided. Furthermore, the size of peripheral components (high pressure pumps, lubricant coolers and containers) can be reduced, which leads to a lower overall energy use (Grundfos, n.d.)

Appropriate environmental indicators

The appropriate environmental performance indicator for this BEMP is the:

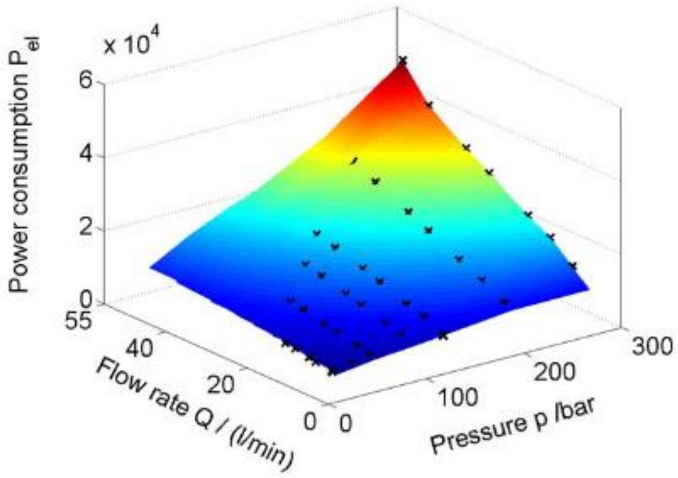
- Consumption of lubricoolants per processed part (l/part)

Cross media effects

The power consumption in the case of high-pressure lubricoolant supply technique is rather higher compared to the conventional flood cooling techniques. The lower temperatures in the cutting zone are achieved only by applying higher pressures and thus increasing electricity consumption of the lubricant supply pumps, as it is showed in Figure 4.4 (Klocke et al., 2015). Also, in some cases the volume of luricoolants applied in the machining processes is higher compared to other techniques[53].

[53] For that reason, high-pressure lubricoolant supply is preferable for prototypes or products with added value where the value of the final product outbalances the higher energy use and costs of the fabrication.

Figure 4.4. Electrical power consumption depending on flow rate and pressure



A drawback of cryogenic grinding is the considerable increase in the required spindle power when LN_2 is applied. Additionally, the environmental effect of cryogenic grinding in comparison to conventional cooling strategies should always consider the amount of energy required to produce the LN_2. The flow rate of LN_2 and the service life of conventional metalworking fluids would significantly influence the energy efficiency of such systems (Jawahir et al., 2016).

Overall, the production of LN_2 implies considerable energy use. Nevertheless, this can be outbalanced because lower temperatures during the metal cutting process results in increased hardness and toughness in the cutting tool material, which in turn allows higher material removal rates leading to increased productivity that further leads to lower energy consumption. Together with reduced tool wear, the total energy use can be reduced compared to e.g. flooding, if process the performance is kept on a high level (Jahal et al., 2010).

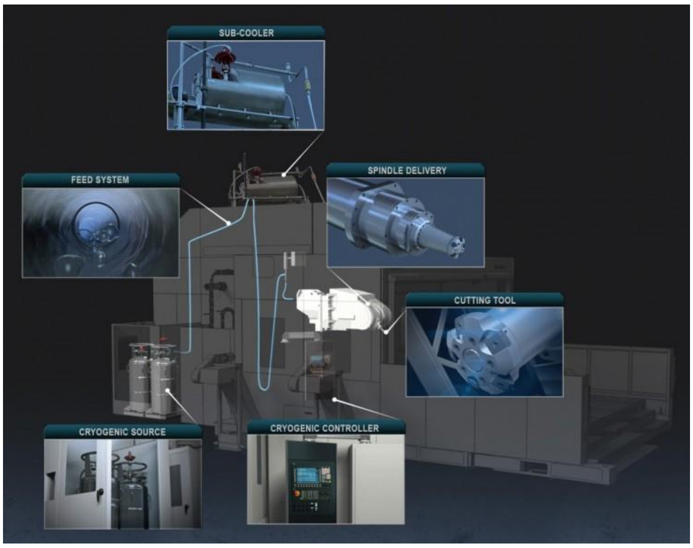
Operational data

Cryogenic technique

The most commonly used cooling substances are liquid hydrogen (boiling point: 20.268 K), Liquid Nitrogen, LN_2 (boiling point: 77.35 K), liquid oxygen (boiling point: 90.18 K) or dry ice/CO_2 snow (sublimation point: 194.5 K or -78.5 °C).

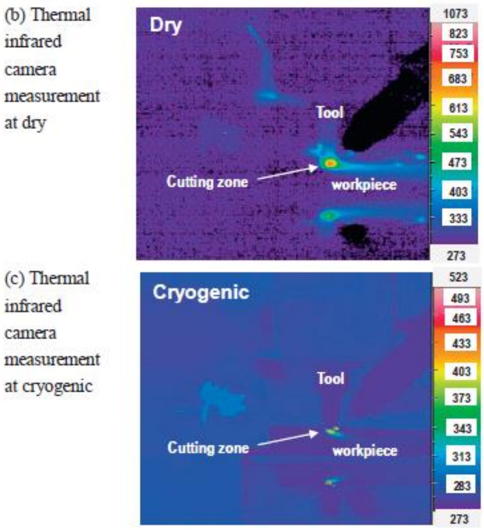
Cryogenic machining systems consist of different components including the source, feed, sub-cooler, cryo-control, the spindle and the tool (see Figure 4.5).

Figure 4.5. Cryogenic machining system developed by 5ME



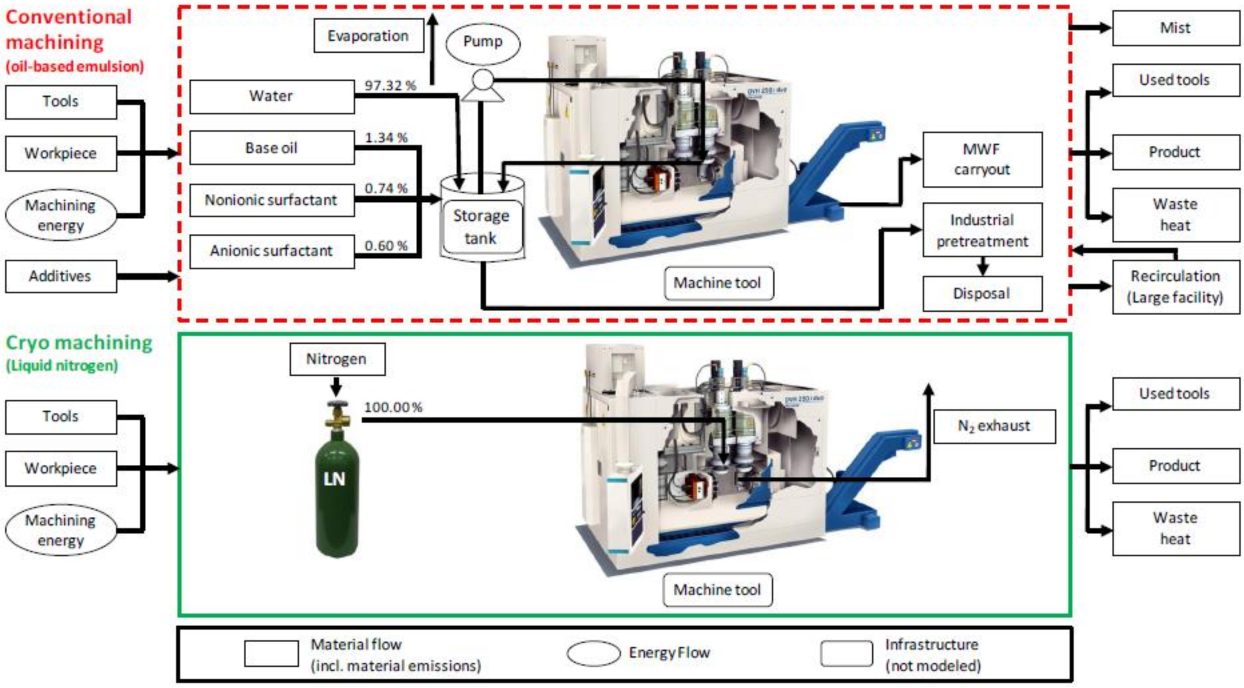
The source is the storage of the liquid nitrogen and can be constituted by internal as well as external vacuum containers or cell based storage. The feed consists of vacuum jacketed insulated lines reaching from the source to the spindle, ram or turret system. It is responsible for the transport of LN_2 at -433°F until the point of application. By removing pressure generated heat out of the system which returns the LN_2 flow back to -433°F and condenses back to 100% liquid, the sub cooler helps preventing the formation of gases from downstream heat leaks and pressure drops. The regulation of the flow rate is conducted via the cryo-control (VCFS control), a programmable control based system that allows for operators to program the automatic control, which signals how much flow is appropriate and allows for auto override to emergency shut-off as well as to overflow the system. An insulated spindle system allows the cryogen to transfer through the spindle, turret, or ram without influencing the functional temperatures of these critical machine components. Specifically designed tools are available for proper functionality and safety (5ME, n.d.).
In an experiment performed by Aramcharoen and Chuan (2014), the cutting temperature during milling processes in an nickel based alloy (Inconel 718) can be reduced by 473 K for LN_2 cryogenic cooling when compared to dry cutting.

Figure 4.6. Thermal infrared imaging camera measurement of cutting temperature (Aramcharoen and Chuan, 2014).



As highlighted in Figure 4.7, cryogenic cooling systems often are less complex compared to oil-based lubricoolant systems in conventional machining processes. Pumps, storage tanks as well as disposal containers can all be replaced by a single liquid nitrogen cylinder directly connected to the machine.

Figure 4.7. Comparison of lubricoolant flows in conventional and LN_2 application in the case of cryogenic machining (Pušavec and Kopač, 2011)



High-pressure jet lubricoolant supply

Mayfran, a manufacturer of machine tool products, launched a project together with Grundfos, with the aim of developing a new technology platform for high-pressure cooling lubricant supply that eliminates the disadvantages of an unregulated cooling lubricant pump. The so called "Vari-flow" process combines a manual transfer switching equipment (MTSE) screw pump (up to 130 bar) with a speed controlled motor to automatically adjusts the flow pressure/volume to the requirements of different drills (Figure 4.8).

The operator has access to an adaptive system that responds to process conditions and actively adjusts to achieve an ideal state. This leads to lower energy costs, higher process quality and improved process security, achieved through reduced tool wear and better surface quality (Grundfos, n.d.).

Figure 4.8. Platform for high pressure cooling lubricant supply (Mayfran GmbH)

As regards energy efficiency and costs, the flow rate and pressure have to be optimised. In a specific case, the optimum pressure and flow rate were 15 MPa and 31 l/min, respectively. The cleaning efficiency is influenced by the nozzle design, the orifice area and the jet opening angle (Brinksmeier et al., 2015).

Applicability

This BEMP is broadly applicable to all types of companies, including SMEs. It is more suitable for new built manufacturing sites or renewed installations rather than retrofitting an ongoing process. Additionally, the type of materials processed heavily influences the applicability and eventually choice between the two lubricoolant application techniques.

For instance, cryogenic cooling shows great potential especially for difficult-to-cut[54] (or hard to machine) materials since it helps in heat reduction, temperature distribution and improves the entire process efficiency including economic aspects. Besides the lower heat generation, increased cutting speed and higher productivity can be achieved. It can be applied to almost every process or machine. However, given its energy intensity, it is more suitable for small series or manufacture of products with high added value. In other words, the manufacturers shall assess its feasibility against their processes, product portfolio etc. before its application. This, in combination with the lack of in-house technical knowledge and expertise may constitute a significant barrier for the application of this BEMP, especially in SMEs.

Nevertheless, in high-speed machining, cryogenic cooling represents a key technology for aerospace, engine, mould/die and automotive industries (Aramcharoen and Chuan, 2014).

High-pressure jet lubricoolants supply technique can be applied for processes such as chip breakage as well as for deburring, edge rounding, surface smoothing and surface hardening. Most efforts in this field concern the aerospace industry regarding difficult to cut material, especially in the turbine production where high-temperature resistant materials such as nickel- or titanium based alloys have to be machined. However, high-pressure jet supply lubricoolants supply needs to be adapted to every process at hand. Higher electrical energy demands, increased costs of the necessary aggregates as well as special tools and holders require an improved productivity or manufacturing of added value products in order to be beneficial.

[54] Especially for hard-to-machine materials such as hardened, stainless or alloy steels, CGI, Inconel, Titanium, Stellite etc., the strong cooling effect can reduce cycle times, energy use and tool wear.

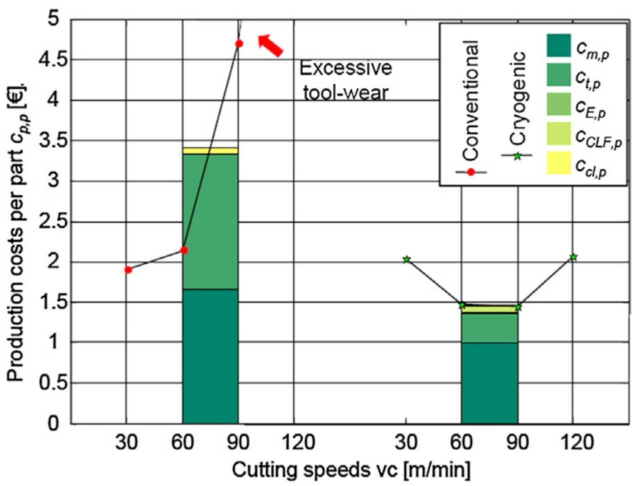
Economics

The economic feasibility of alternatives to conventional lubricoolant systems depends on different factors. Generally, conventional dry machining seems to be more expensive to use compared to cryogenic and high-pressure jet-assisted machining. However, in the case of lower cutting speed, economics of conventional processes might work out better. Cryogenic and high-pressure jet-assisted machining should only be applied when high efficiency and elevated productivity are required, mainly connected to the machining of materials that are difficult to process (Jawahir, 2016).

Lu (2014) mentioned that economics of cryogenic machining is directly related to the flow rate and the machining performance benefits from its utilisation. Considering the improved functional performance of cryogenically manufactured components, in terms of total life-cycle cost savings, the initial investment cost for cryogenic processing are more than justified.

Pušavec and Kopač (2011) determined the total production costs per part for cutting processes combining tool life and production times for different cutting speeds, as presented in Figure 4.9. The total production costs for different cooling conditions are indicated as stacked bars that represent the individual contributions to the total at a cutting speed of 75 m/min. The solid line shows the changing trends of the total production cost per part due to the changes in the cutting speed.

Figure 4.9. Production costs comparison for Inconel 718 (Pušavec and Kopač, 2011)



From the presented results, it is possible to state that conventional machining is significantly more expensive than cryogenic machining, especially in the case of high cutting speeds. Only at lower cutting speeds conventional machining appears economically more convenient, even if the suboptimal production rate has to be taken in consideration.

Regarding the contribution to the overall production cost, machining costs and costs for changing the cutting tool are highest in conventional machining. Coolant costs have a much bigger share in cryogenic cutting. While conventional machining has low coolant cost, the costs of cleaning are higher, which are negligible in the case of cryogenic machining (Pušavec and Kopač, 2011).

Driving force for implementation

The reduced tool wear and process times are the main drivers for implementation of this BEMP.

Reference organisations

Mayfran GmbH, specialists in swarf and lubricoolants management during machine tool operations, Am Gut Wolf 3 D-52070 Aachen

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WZL, RWTH Aachen, 22.08.2017, available online at: http://www.wzl.rwth-aachen.de/__C1256E970034898A.nsf/html/en_6b7854669f9926f4c1257b740062c547.htm, last access: 6th September 2017

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4.3 Incremental Sheet metal Forming as alternative for mould making

<table>
<tr><td colspan="6">SUMMARY OVERVIEW
For the production of small series, it is BEMP to apply incremental sheet metal forming (ISF) as an alternative for mould making. This allows the manufacturing of complex products with a higher material efficiency.</td></tr>
<tr><td colspan="6">Relevant stages</td></tr>
<tr><td colspan="2">Cross-cutting</td><td colspan="2">Optimisation of utilities</td><td colspan="2">Manufacturing</td></tr>
<tr><td colspan="6">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td></tr>
<tr><td colspan="6">Environmental performance indicators</td></tr>
<tr><td colspan="6">- Energy use per manufactured product (kWh / kg finished product or manufactured part)
- Resource efficiency (kg finished product / kg of material input)
- Environmental benefits of switching to ISF are proven by a full LCA or a simplified LCA based on quantitative analysis (Y/N)</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="4">This BEMP is broadly applicable to all types of companies in the sector, including SMEs. ISF can be used for a wide variety of materials and it is more suitable for complex product geometries and for small series of production and prototypes. However, companies prior to switching to ISF technique, may carry out a life cycle assessment to understand environmental benefits.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="4">The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement in, at least, the following indicators:
- energy use per manufactured product
- resources efficiency
- consumption of metal working fluids[55] per manufactured product</td></tr>
<tr><td colspan="2">Related BEMPs</td><td colspan="4">N/A</td></tr>
</table>

Description

In the fabricated metal products sector complex shaping of sheet metal, e.g. double curved surfaces, nowadays is performed by processes like deep drawing, rubber forming, hydroforming, stretch forming, explosive forming or spinning. All of these forming techniques require the use of one or several moulds. The production of these moulds is time and material intensive. Typically a mould is made out of metal (due to its required wear resistance) and is milled starting from a solid block of metal. This means that a lot

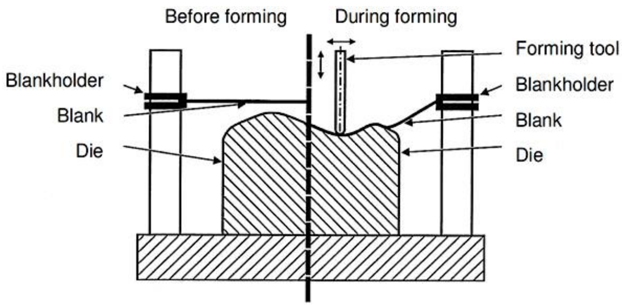
[55] N.B. Metal working fluids consist of oils, oil-water emulsions, pastes and gases. Therefore, it can be of either solid, liquid or gas form, influencing thus the type and the equipment needed for their application and eventually the metrics used in the benchmark to monitor improvement in the environmental performance of this aspect.

of energy is needed to mill and a lot of material finally ends up as flash. After milling, the mould has to be polished. These processes are economically viable for large production series. For low production series (e.g. in deep drawing), sometimes plastic moulds are used. These plastic moulds wear out faster, but are cheaper (Proven Concepts BV, 2014). Also for the production of composite parts, often metal moulds are used.

Since production is more and more focused on smaller series, down to one of a kind and prototypes, another forming process such as incremental sheet metal forming (ISF) can offer a solution to some of the problems linked to the conventionally applied machining processes. Therefore, this BEMP deals with ISF as an alternative for mould making. ISF is an umbrella term for a range of processes in which a sheet is formed incrementally by a progression of localized deformation. The key advantage of ISF over the conventional sheet shaping processes is that no specialized dies are required; a wide range of shapes can be achieved by moving a spherical-ended indenter over a custom-designed numerically controlled tool path. Hence ISF is ideal for small-batch-size or customized sheet products (Cambridge University, 2009). However, it is recommend that manufacturers carry out a full (or simplified) LCA to understand whether the switching to ISF results in significant environmental benefits and thus it is worthwhile.

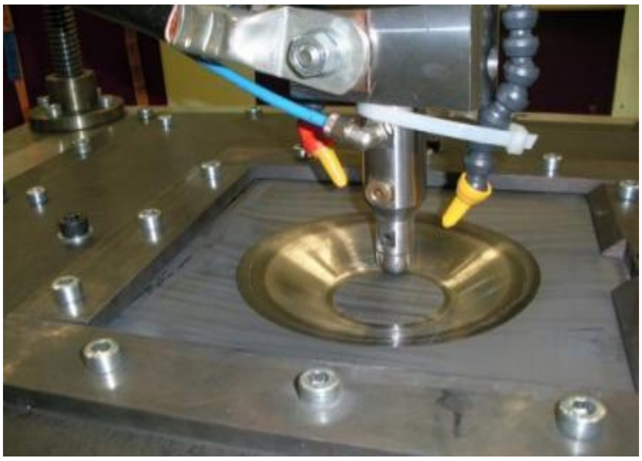
ISF was initially designed with the aim to reduce necessary equipment and to increase production flexibility. In the simplest configuration (Single Point Incremental Forming, SPIF) the process build-up consists of a sheet clamping equipment and a hemispherical punch that incrementally shapes the sheet toward a desired geometry by a proper trajectory on the sheet itself (Figure 4.10). Such incremental action allows the manufacturing of complex products avoiding the use of rigid and dedicated clamping system. Thereby process costs and times are reduced. The technology is a suitable alternative to traditional stamping when small lots of high differentiated products have to be manufactured (Ingarao et al., 2012).

Figure 4.10. Process principle of incremental sheet forming, ISF (ISF-Light, 2012)



ISF can be applied for forming a large variety of geometries and has no need for expensive tooling. ISF can be used for a wide range of materials, e.g. aluminium, stainless steel, steel, zinc or magnesium. The deformability depends on the material characteristics and thickness. Processing of parts is much slower than for the classical shaping processes, but the lead times (time-to-market) can be much shorter and there is almost no influence when design changes occur. ISF can be used for making sheet metal moulds for the production of composites, e.g. Resine Transfer Moulding (RTM) moulds. Since the only forming process is a contouring operation, the processing time for making such moulds is significantly shorter than milling a block of metal, thus reducing energy and raw material use (Figure 4.11).

Figure 4.11. Incremental sheet metal forming installation (INMA, 2014)



Achieved environmental benefits

The major environmental benefits are the reduction of raw material and energy use. The reduction of energy use is achieved due to a shorter production time. No energy is needed for actuating the tooling and no logistics are required for the waste, as no waste is produced. Also, due to the nature of this process, noise and vibration levels are low. Furthermore, environmental benefits of implementing ISF are related to a reduced time to market, which has an impact on overall resource use. Ingarao et al. (2012) indicated that, based on experiments, the implementation of ISF can lead to a reduction of 10% material use compared to more traditional forming process, in this case stamping.

Ingarao et al. (2013) also analysed the energy use of single point incremental forming processes. Furthermore, they presented a comprehensive energetic analysis of the single point incremental forming process. All machine tools architectures commonly used to perform SPIF operations have been taken into account: energy use/power consumption analyses have been conducted for a CNC milling machine, a six-axes robot as well as the dedicated AMINO machine tool was analysed. It was observed that as a function of the material strength the power/energy demand monotonously increases. The so-called material contribution share on the total energy demand accounts for up to 22% for the material with the highest tensile strength in the considered material set. As far as the sheet positioning is concerned, a significant influence has been observed on the robot platform: to form the strongest material considered in the experimental campaign, a variation of 9% in energy consumption was observed by a limited position shift. The results lead to the conclusion that a proper machine tools selection linked to an environmental conscious process parameters selection could result in large electric energy reductions.

Dittrich et al. (2012) presented an exergy analysis of ISF processes and compared two ISF variants (single and double sided) to conventional shaping and hydro shaping processes. From an environmental perspective, ISF is advantageous for prototyping and small production runs up to 300 parts (Kellens, 2013).

Appropriate environmental performance indicators

Appropriate environmental indicators that monitor the environmental performance of this BEMP are summarised below.

Resource efficiency (kg finished product / kg of material input)

This indicator measures the efficiency of the ISF process and measures the amount of material used in the finished products.

The energy use for the operation of the ISF technique is measured by the following indicator.

- Energy use per manufactured product (kWh / kg finished product or manufactured part)

Manufacturers shall evaluate and assess the feasibility of moving from conventional machining to the ISF technique and if eventually meets the actual production/manufacturing needs. A life cycle assessment can be a useful tool to validate environmental benefits of switching to the ISF. The indicator can be:

- Environmental benefits of switching to ISF proven by a full LCA or a simplified LCA based on semi-quantitative analysis (Y/N).

Cross-media effects

The implementation of ISF in a company in the sector might be less appropriate in case of heavy duty, high volume or high pressure applications. For some simple sheet metal forms that can be manufactured by stamping the energy use of the single point incremental forming process (SPIF) can be higher than the energy needed for more traditional stamping. Form complexity and thickness of the metal have a significant impact on the energy use during production (Ingarao et al., 2012).

Operational data

The size of the manufactured metal depends on the platform and setup size of the installation and typically ranges from 100 x 100 mm up to 2,000 x 2,000 mm and even larger. The following platforms can be used, i.e. milling machine, industrial robot, a machine with special features (Figure 4.12). Plate thickness typically varies between 0.5 mm and 2-3 mm.

Figure 4.12. Platforms used for ISF, from left to right: CNC milling machine, industrial robot, dedicated machine (Aminio, 2015)

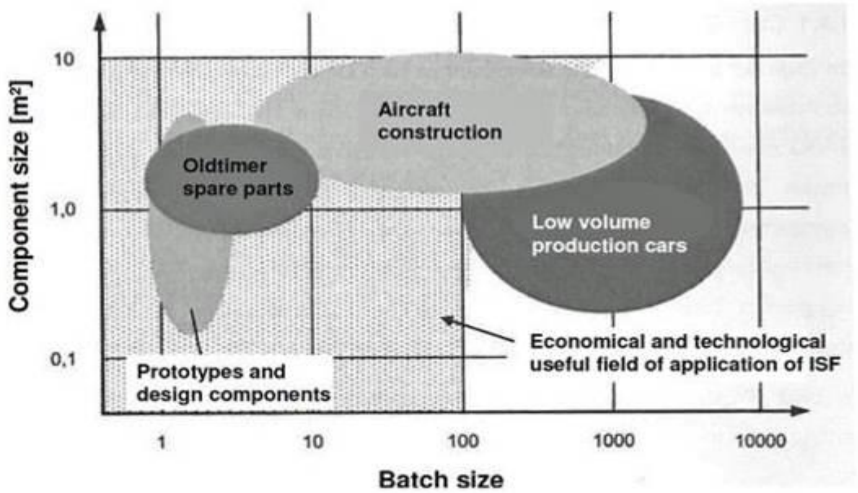
Sirris is a Belgian technology provider, which produces three kinds of machines, depending on how the blank sheet is supported. Two point incremental forming uses a full or partial matrix to support the workpiece during formation; single point incremental forming where a matrix is not used and the sheet is held in a clamp, usually in combination with a backing plate; kinematic incremental sheet metal forming, which is a variation that uses two pins where one of them acts as the shaping tool, while the second pin gives local support to the other side of the sheet (Sirris, 2017).

Applicability

The manufacturing of parts with the ISF technique requires a case by case approach, considering material properties, features, existing manufacturing capabilities, batch size etc. Considering the relatively low industrial adoption of this technology companies from the sector often choose to be supported by competence centres for implementation of this technology.

ISF can be used for a wide variety of materials and product geometries although it is more suitable for small series of production and prototypes. Since, in most cases, no dedicated expensive tooling is required, start-up time is short and investment is low for prototypes or for manufacturing single parts, small and medium batch sizes. Ames (2008) indicates several current and potential fields of application of ISF, based on the component size and the batch size (Figure 4.13).

Figure 4.13. Current and potential fields of application of incremental sheet forming (Ames, 2008)



For large products a support tool can be required. The product geometry defines the need and complexity of the support tool. A simple tool can be used in products where the walls do not include horizontal surfaces. Then the sheet can be supported on the highest point of the product and form the walls without any extra support. Examples of these kinds of products and support tool are shown in Figure 4.14.

Figure 4.14. Supporting tool in the background of the mould for a bathtub (Nordic Industrial Fund, 2003)

Economics

Possible savings related to the implementation of ISF are related to a lower production cost compared to a traditional forming process, i.e.:

- energy cost;
- material cost;
- time to market;
- tooling.

Obviously the savings depend on the part size and shape. A rather shallow part may require only 10% of material removal by milling, while a deep part may require up to 90% of material removal by milling. It’s clear that in the second case, the savings on energy cost, material cost and time are a lot higher than in the first case. ISF is cost effective for small to medium sized series, as it does not depend on complex and expensive tooling. ISF is typically considered cost effective for a production volume up to 300-600 pieces. From that volume investing becomes feasible.

Figure 4.15 shows the design of a piece which was used for the calculations of the costs. The forming costs are about 5 to 10% of the costs of traditional pressing, but the production speed is also lower. Despite of the slower speed the method is more efficient when producing single parts or short series (Lamminen et al, 2003).

Figure 4.15. Dimensions of the piece used in the costs calculation (Lamminen et al, 2003)

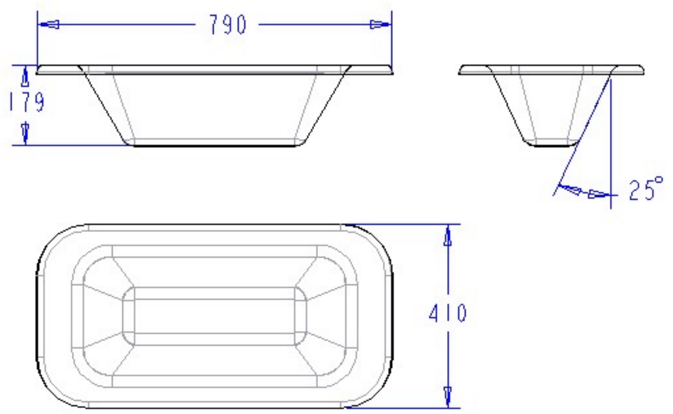


Table 4.4 makes a cost comparison between deep drawn product versus two ISF processes.

Cost of setting up and NC programming is €50 in both cases. Cost of deep drawing dies is estimated at €12,800.

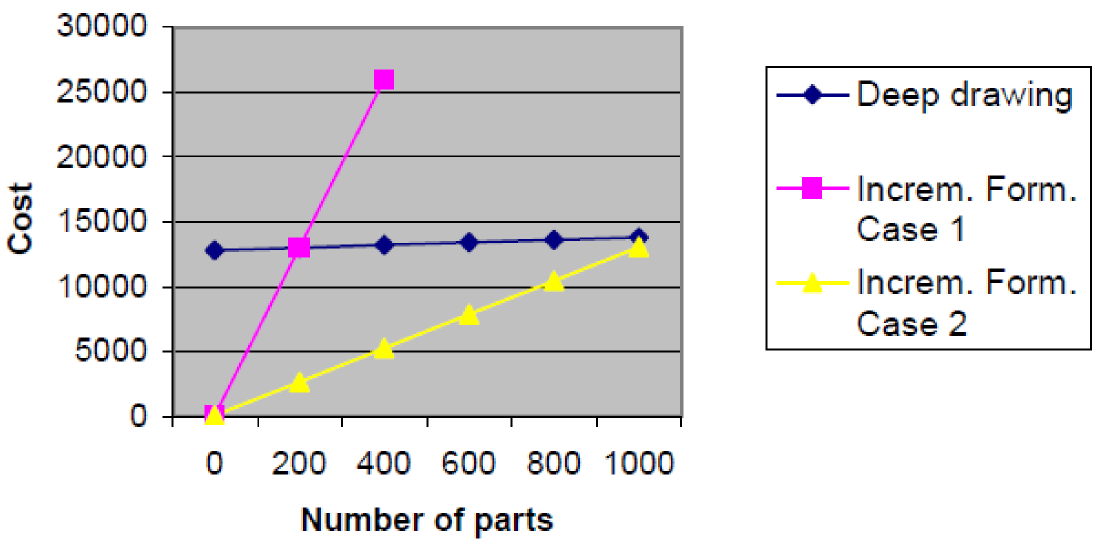
Table 4.4. Comparison of deep drawing and incremental sheet forming parameters and unit costs (Lamminen et al, 2003)

	Deep drawing	*ISF 1*	*ISF 2*
		horizontal forming speed 15 m/min, vertical feed 0.2 mm per step, total length of	horizontal forming speed 30 m/min, vertical feed 0.5 mm per step, total length of forming path

	Deep drawing	*ISF 1*	*ISF 2*
		forming path 1,465 m	585 m.
Operating costs (EUR)	40	40	40
Parts per hour	40		
Cycle time (min)	1	1h 37 min	19.5
Part cost (without material)	1	64.8	13

According to these calculations, incremental forming is considered profitable for production volumes lower than 1,000 parts. If the production volume is higher, deep drawing is considered more profitable, at least when using the forming parameters recommended by Aminio (2015). If the research parameters are used, deep drawing is considered profitable at a production volume of 200 parts. Figure 4.16 shows a diagram of the cost for incremental forming and deep drawing as a function of the production volumes.

Figure 4.16. Cost comparison diagram for incremental forming and deep drawing



The cost depends highly on the product geometry and can thus vary a lot. This cost calculation is merely illustrative and although it can be used as general reference, it cannot be applied for other types of products without further research.

Driving force for implementation

The main driving forces for implementing ISF are both environmental (energy and material use) and economical drivers (time to market, lower production costs). Moreover, LCA can be a useful tool to validate environmental benefits of switching to the ISF

Reference organisations

Beauvary (DE): Beauvary's activities focus on small-batch sheet metal manufacturing for automotive and non-automotive, http://www.beauvary.com/index.php

Ford US uses the ISF for low volume products (3ders, 2013).

OCAS (BE), OCAS anticipates its' customers' needs by developing alloys and coatings, by producing and testing samples and co-develop steel applications. OCAS is equipped with state-of-the-art R&D tools and facilities in its laboratories. The research centre valorises know-how by product and solution development (e.g. ISF), http://www.ocas.be/.

Sirris (Belgium) - By combining ISF with other sheet metal work processes, it is possible to achieve further reductions in production costs. This in turn should lead to greater design freedom and therefore new products and applications, http://www.sirris.be/Incremental-Sheet-Forming

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4.4 Reduction of standby energy of metal working machines

SUMMARY OVERVIEW					
BEMP is to reduce the standby energy use of metal working machines by switching off (and on again) the machines in their most efficient way, either manually or automatically (re-programming the control system) or by purchasing more energy-efficient machines in which a "green" standby mode (with very low energy use) is integrated. This operational way is often based on several subunits that can be switched off individually instead of putting the entire machine simply on standby. An additional approach is reducing the duration of standby phases, especially for machines with high energy use during downtime, through an optimisation of production planning.					
Relevant stages					
Cross-cutting	Optimisation of utilities	**Manufacturing**			
Main environmental benefits					
Resource efficiency	Water	Waste	Emissions to air	**Energy and climate change**	Biodiversity
Environmental performance indicators					
- Energy use per manufactured product (kWh / kg of finished product or manufactured part) - For individual relevant machines: Total energy use per and year (kWh / year) - For individual relevant machines: energy use during downtime (kWh / hour) (kWh/hour) - Percentage of machines having a switch-off/do-not-switch label (%)					

Applicability	The BEMP is broadly applicable in all types of companies from the sector, including SMEs.
Benchmarks of excellence	All metal working machines have either a green standby mode or a label indicating when they should be manually switched off
Related BEMPs	BEMP 2.3

Description

The reduction or even minimisation of energy use during the non-productive time of the manufacturing operations, can contribute to the increase of the overall energy efficiency of the manufacturing site. The energy use during standby mode often represents a significant share of the total energy demand of manufacturing processes (Duflou et al, 2011). Auxiliary processes such as coolant circulation, compressed air, electronics and fans consume up to 30% of the total energy demand during standby mode (Kellens et al, 2013). These processes are required to insure machine readiness (availability), data transfer and to avoid long warm up periods (Table 4.5). In addition, pumps, electrical engines and other components remaining active during standby mode can still be subject to wear and aging, even if the machine is currently not in use (exposure to heat or cooling, chemicals, etc.).

Table 4.5. Overview of auxiliary processes during standby mode (Duflou et al., 2011)

	Component	Function
Spindle Drivers	Main Spindle Motor	Besides rotary motion, holds as well as centres work piece
	Rotary Tool Spindle Motor	Rotary motion for cutting tool
Servo Drivers	i-Axis Motor	Linear motion for cutting tool
	Tailstock Spindle	Besides rotary motion holds as well centres workpiece at tailstock
	Turret Motor	Rotary motion for cutting tool change
Hydraulic System	Hydraulic Unit Motor	Rotary motion for pump to supply clamping pressure
Cooling Lubrication	Lubricant Pump Motor	Rotary motion for pump to supply lubricant
	Oil Cooler Pump Motor	Rotary motion for pump to supply oil cooler circuit
Control System	Spindle Amplifier / Frequency Converter	Transfer numerical control signal for spindle rotation speed into adjusted electrical signal
	Servo Amplifier / Frequency Converter	Transfer numerical control signal for servo feed into adjusted electrical signal
Auxiliary System	Computer and Display	Processing and visualisation of program
	Lighting	Lighting the working area
	Fan	Airflow generation cooling for cooling electrical components
Periphery System	Coolant Pump Motor	Rotary motor for pump to supply coolant circuit with pressure
	Chip Conveyer Motor	Rotary motion for chip conveyor
	Tool Change Arm Motor	Rotary motion for tool change

During standby mode, the machine is not contributing to any useful work and thus its energy use (some energy is used to keep the machine at working temperature and avoid ulterior preheating or precooling) can be reduced to a significant extent.

Standby energy can be reduced by lowering the overall power demand, or through limiting the duration of standby phases. The first can be obtained by selectively switching off non-required subunits whereas the latter can be achieved through an optimisation of production planning (Kellens, 2013).

The first step towards the reduction of energy use of the metal working machines is to detect the most energy using (working) machines in the manufacturing site. Secondly, it is essential to understand the operations and processes of the most energy using machines according to the production schedule and manufacturing needs.

Therefore, manufacturers can decide to install digital systems or re-programming the control systems that will allow the most energy using machines to switch on/off automatically or manually. Alternatively, they can opt for more energy efficient metal working machines.

Organising switching on/off

The setup of a switching on/off scheme for the working machines of the manufacturing site needs to consider all the operational parameters of the processes and also to ensure that the settings for the machining operations are kept in the memory of the control systems of the machines and are not lost.

On top of the above mentioned parameters, the switching on/off schemes have to consider the average arrival time interval of workpieces, the production batch and whether start-stop energy use is less than the no-load power consumption in the standby process. It is reported that frequent start-stops affect the stability of the machine tools and eventually its life time (Shandong, 2015).

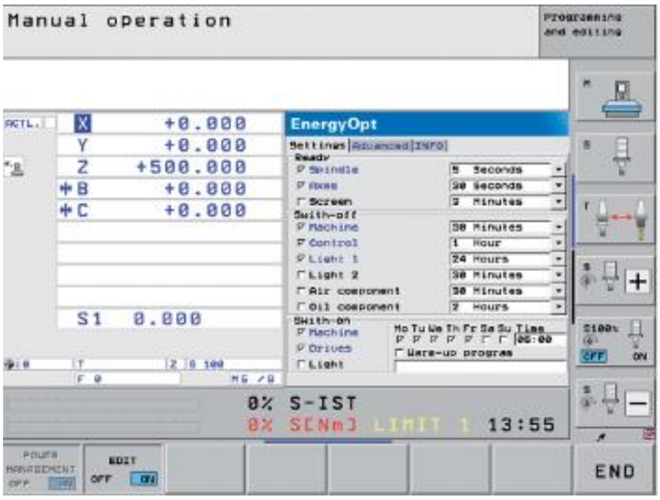
Therefore, it is essential that the manufacturers devise carefully a production planning with the aim to group the machining operations based on their energy intensity, duration according to the actual demand by the customers.

Re-programming the control system

One possible approach to reduce the energy use during standby is to develop a guidance list that indicates individually for each machine, which components/auxiliary functions can be turned off at different points in time e.g. after one to several hours of inactivity. To retrieve the necessary information a baseline analysis of the manufacturing site's overall energy use should be conducted[56]. This includes the identification of both the processes and single machines that are the major energy users in terms of baseline and standby energy. The obtained data can then be entered in the software of the control system (e.g. Computerised Numerical Control - CNC unit), in order to make the relevant information accessible to all workers/operators involved. In this way the control system can inform the operator about prolonged inactivity or even switch off certain components automatically.

An example of a CNC interface is presented in Figure 4.17. Several functions are built in that allow the machine operator to shut down non-essential functions and/or to automatically activate them before the shift starts. This ensures the operator can start working with a pre-heated machine allowing an immediate start.

Figure 4.17. Energy management in a CNC (Heidenhain, 2010)



Purchasing new machines with green standby mode

[56] For further information on energy management see also BEMP 2.3 on Energy management

New built manufacturing sites or existing ones who are in the process of renewing their metal working machines can purchase more efficient equipment, which can result in higher productivity and lower maintenance. Modern metal working machines can switch off their auxiliary components and turn on green standby mode. During the green standby mode the only power consumed is for running the control system.

The new machines with green standby mode usually incorporate other energy efficiency features, which are outlined in the BEMP 4.7 on Hybrid machining.

Placement of labels on machines

A much simpler measure without necessarily the use of CNC units is the placement of labels on the relevant machines that provide information for the operator about the optimal standby and downtime management of the machine.

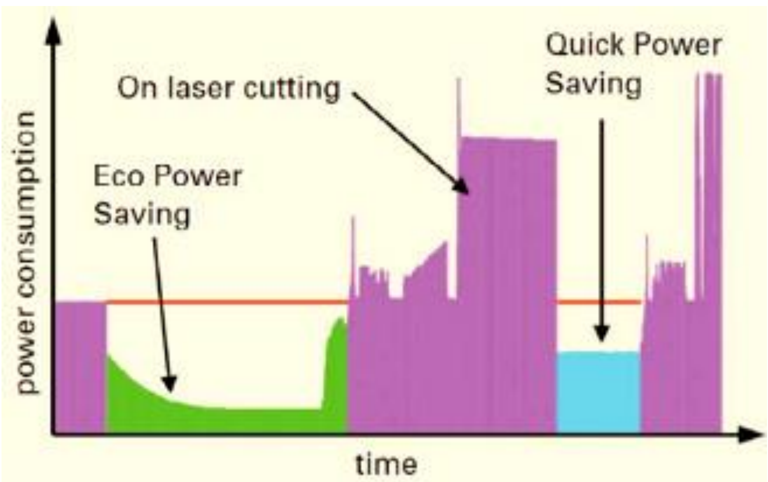
Achieved environmental benefits

The major environmental benefit of shutting down non-essential functions and components during standby mode of working machines in the metal fabricating sector is the reduction of overall energy use and consumption of consumables e.g. lubricants. For instance, conventional drilling machines require approximately 150-200 litres of lubricant whereas machines with standby mode can consume up to 25-30 litres of lubricant. This leads to simpler maintenance and less use of consumables (Equipment news, 2019).

As regards to the energy use, in the case of the Electrical Discharge Machining (EDM), the switching off of the pumps can result in significant energy savings. In particular, the pumps consume an average of 60% of the total energy used and can be switched off during the stages of preparation, repair or standby.

For a CO_2 cutting lasers the standby energy (Figure 4.18) can be reduced considerably by introducing power saving modules in the controller (Kellens et al. (2013). The system de-activates non-essential subunits and ensures quick reactivation when the machine turns back into operation phase. This results in a reduction of up to 66% of standby power requirement.

Figure 4.18. Energy profile for a CO_2 laser (Kellens et al. 2013)



The devise of a production planning contributes to the reduction of downtimes and wear of the equipment (machines and their auxiliary components), increase of the productivity, and the avoidance of the energy peaks due to start-stop of the working machines.

Summarising, the most important achieved environmental benefits are:

- Reduced energy use for machines that are currently not in use
- Reduced emissions due to lower energy use
- Extended tool lifetime leading to lower raw material input for new equipment
- Less use of consumables e.g. lubricants.

Appropriate environmental performance indicators

The appropriate indicators that measure the energy use of each relevant machine are the following ones:

- Total energy use per relevant machine and year (kWh/year)
- Total energy use during downtime (kWh / hour)

Manufacturers can also perform an analysis of their machining operations and produce and place labels on the relevant machines. The share of the relevant labelled machines out of the total number of machines in a manufacturing site is a useful indicator:

- The percentage of machines having a switch-off/do-not-switch label (%).

Cross media effects

In principle there are no cross media effects from the implementation of the measures of this BEMP. However, in some cases the energy use may rise during the switching on/off of the various machines (energy peaks). This issue, in the case of electric motors, can be tackled by installing variable speed drive motors.

Operational data

Gestamp Umformtechnik GmbH is a fabricated metal product manufacturing company located in Germany that introduced energy saving measures at two hydraulic presses. They started with monitoring the energy use on the two presses. Afterwards, they assessed the results in an energy monitoring system.

One hydraulic press has a maximum punch force of 3.500 tons and is operating from 16 to 24 hours per day, five to six days per week. The implementation of an automatic-switch-off for hydraulic main-pumps at every longer downtime (including stops, interruptions, breaks, repair, etc.) resulted in energy savings of approximately 15% of the total energy use.

The second hydraulic press operates 24 hours per day, five to six days per week. In this press, a manual switching on/off by the operators was introduced. Similar energy savings to the first machine were also achieved in this press (~15% of the total energy use of the press).

Fanuc is a technology provider of machines with CNC systems, such as laser sources with two different standby modes, the so called "quick power saving" and "eco power saving". The manufactured machines switch off single components such as lighting, ventilation, cooling/lubricant supply or compressed air in downtimes (or standby periods). Energy savings between 34% and 70% thanks to the incorporation of a green standby mode are estimated. During the "quick power saving" mode, the machine can be switched back to operational mode quickly and the discharge is stopped. In the case of "eco power saving" mode the turbo blower is also switched off. In machining operations with 14.8% of standby time, both standby saving modes resulted in significant energy savings up to 16.0 kWh, per 8h shift (Fanuc, 2015).

Applicability

The reduction of energy use in standby mode is broadly applicable for all types of companies from the sector, including SMEs. This BEMP is more suitable for new-built manufacturing sites or in major retrofits planned.

Simple labels about best management options can be placed on machines very easily and at really low costs.

Consistent switch-off of auxiliary components can pose some additional difficulties. Suddenly removing the waste heat from auxiliary components and the connected temperature-stabilizing effect can cause thermal displacement in the machine frame, resulting in defective parts, which impair the energy balance of a production process. The selective switch-off of auxiliary components therefore functions best for machines with little inclination to thermal displacement. In any case, careful planning of the energy saving effects is a prerequisite (Heidenhain, 2010).

Some machines, when they are turned on, cause an energy peak due to activating all involved systems for preheating or –cooling as well as preparation. Especially Electrical Discharge Machining (EDM) generators and laser sources suffer from cyclic loads, resulting in the common practice of not shutting down production machines unless longer unproductive phases are expected. For electric motors, this can be solved by installing variable speed drive motors.

Economics

In the case of Gestamp GmbH, the switching-off of energy demanding components in non-productive times, e.g. breaks, interruptions, periods of repair or maintenance in the two hydraulic presses, resulted in annual savings from €90,000 to €140,000 (Gestamp, 2016).

The upgrade of the control system of the machine, which is mainly a software based measure, by including CNC systems and green standby modes is a low cost measure and is feasible by SMEs as well. Typically, the implementation can be realised with short payback times and without any modification of the hardware. In many cases hardware is not affected so that the only costs derive from software acquisition and installation procedure.

The installation costs depend on the complexity of the system and on the presence of already installed monitoring systems, which strongly affect the time necessary to collect relevant data. In the case information is available, optimising measures have to be tested and evaluated possibly leading to fluctuations in production, which can however be compensated if the consecutive installation is successful.

Driving force for implementation

The main driving forces for implementation are the reduction in energy use resulting in lower associated costs. Furthermore, a reduction of greenhouse gas emissions, depending on the type of energy source can be motivating for companies.

Reference organisations

Gestamp Umformtechnik GmbH, Bielefeld (DE) was able to achieve relevant energy savings by introducing measures on their hydraulic pumps that optimised their downtime management. This further led to GHG emission reductions and monetary savings.

Metaplast, metal working machines have labels and thus a proper switching out is achieved. Moreover, the machines keep in their memory the settings for the following operations/metal processing and thus it is not necessary to reload them when they are switched on (manually).

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Gestamp Umformungtechnik GmbH, October 2016, Switch-off 2 presses NLA 314+320 - Energy saving, Bielefeld (DE)

4.5 Maintaining material value for metalworking residues

<table>
<tr><td colspan="7">SUMMARY OVERVIEW:
BEMP is to maintain material value by post-processing metal scrap (chips and swarf), in particular through two aspects of metal residue processing:
• segregating flows of metal residues to ensure a high level of purity allowing further recovery and recycling at higher quality grades;
• recovering and segregating cutting oil and metal, for instance by pressing chips and swarf into briquettes.</td></tr>
<tr><td colspan="7">Relevant stages</td></tr>
<tr><td colspan="2">Manufacturing</td><td colspan="3">Supply chain</td><td colspan="2">End-of-life</td></tr>
<tr><td colspan="7">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td><td>Hazardous substances</td></tr>
<tr><td colspan="7">Environmental performance indicators</td></tr>
<tr><td colspan="7">- Oil recovered (l oil/year)
- Oil recovery efficiency (%/of oil in briquettes or separator output)
- Amount of metals recovered on-site (kg/year)</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="5">This BEMP is applicable to all types of companies in this sector, including SMEs and more relevant for the production of large series.
The volume of material working residues must be significant to ensure economic feasibility.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="5">Turning chips and grinding swarf have oil/moisture content respectively lower than 2% and 8%</td></tr>
<tr><td colspan="2">Related BEMPs</td><td colspan="5">N/A</td></tr>
</table>

Description

Scrap metal, in form of swarf (turnings, filings, shavings…) from grinding operations and chips from turning, is generated during metalworking processes. The scrap is collected and mostly stored in bins, taking up valuable space. In addition, small metal pieces and fluids used in the process accumulate as sludge, which is on the one hand difficult to store and on the other hand requires to be properly handled.

Considering that metal scrap as well as sludge might still hold residual value, but is costly to dispose of and difficult to reuse without further processing steps, best practice is to maintain material value by post-processing metal scrap (chips and swarf).

This best practice considers two aspects of metal residue processing:

- segregating flows of metal residues to ensure a high level of purity, allowing further recovery and recycling at higher quality grades;

- pressing chips and swarf into briquettes and simultaneously recover cutting oil.

Segregate flows of metal residues

Recycling of metal scrap is an essential step in the rational use of materials. Avoiding contamination for any metal can ensure that ultimate re-melting can produce higher grade output. In order to successfully recycle aluminium in particular, a proper sorting of aluminium alloys is necessary since aluminium (unlike copper or iron) cannot be refined pyrometallurgically. Therefore, companies from the fabricated metal products manufacturing sector shall separately collect and treat the different aluminium grades in order to allow higher quality in the recycled materials. The proper separation of different grades of alloys results in high value recycling and energy saving. If proper separation is not in place all aluminium chips will end up in the casting industry (low value).

Separation of metals can also be done by means of magnet and eddy current separators or by high-tech sensors or directly by enforcing waste separation during and after production. Metals separation can be implemented at later stage, as metal separation technologies are more relevant for recycling companies and re-smelters. However, separation of metals at the recyclers or re-smelters stage cannot completely replace proper separate collection at the source.

Oil and metal recovery

This allows manufacturers to save on the purchase of new oil or emulsion, reduce costs associated with waste management, and create a new source of revenue. Mechanical treatment or vacuum distillation or washing methods can be put in place to recover the oils or emulsions (Schön et al., 2001).

An efficient solution, already implemented by companies is the briquetting, which actually combines the two elements of this BEMP. Metal briquetting machines can turn scrap metal into compact briquettes that can be easily stored, transported and sold for recycling (Figure 4.19 and Figure 4.20). The processing fluids are collected and can be reused in the various processes or recycled. Therefore, high savings can be achieved from avoidance of purchasing oil and recovering it from the grinding sludge instead. However, as pointed above it is important to collect and treat separately the different waste generated metal streams (e.g. different metals, but also different grades and alloys within the same metal family), in order to allow higher quality in the recycled materials.

Figure 4.19. Example of a briquette machine (Source: RUF Briquetter)

Figure 4.20. Examples of briquetted aluminium swarf (Source: ATM, 2013)

Most briquetting presses are suitable for processing various kinds of swarf resulting from machining of steel, cast iron, stainless steel, aluminium, etc. (keeping in mind the need to avoid contamination if the same machine is used for different streams) and are available in different sizes and filling variants to suit the specific needs of manufacturers and input material. Briquetting can be carried out in-house or outsourced.

Achieved environmental benefits

The main environmental benefits can be summarised as follows:

- Reduction of virgin material use (i.e. metals and lubricoolant)
- Recovery of metals
- Reduction of waste generation (mainly due to recycling/reuse of lubricoolant) and lower oxidation losses (e.g. when aluminium is recycled)
- Reduction of problems associated with handling of loose wet swarf, such as spillages and disposal of spent / waste coolant
- Reduction of dust emissions
- Reduced energy use and carbon footprint (i.e. fewer collection rounds required due to reduced volume (dense briquettes), reduction of energy input required to produce virgin materials due to recycling and reuse; reduction of energy input to separate and refine materials due to correct stream separation.

Appropriate environmental performance indicators

Low oil content is on the one hand important to ensure compliance with applicable regulations, but also relevant for further processing in the steel works, as the adhering oil is undesirable. Oil percentages in turning chips below 2% of moisture have been reported by technology providers[57] whereas values between 8 and 10% have been reported in grinding swarf (Schaeffler AG, 2017). Against this background, the following environmental performance indicators are suitable to measure the performance of this BEMP:

- Oil recovered (l oil/year)
- Oil recovery efficiency (%/of oil in briquettes or separator output)

[57] An example of a briquetting process can be found here: http://www.ars-inc.com/briquetter.aspx

Moreover, the segregation and recovery of the metal residues is an important operation of the manufacturing sites with certain environmental benefits. Therefore, an additional indicator for this BEMP is the:

- Amount of metals recovered on-site (kg/year)

Cross-media effects

The measures of this BEMP are not linked to any cross media effect.

However, briquetting and auxiliary equipment may result in increased electricity consumption and noise (nuisance). Noise can be reduced by insulating properly the machinery. In general, it can be expected that the numerous environmental benefits associated with briquetting and lubricoolant recuperation outweigh the increased need for electricity.

Operational data

Briquetting

Briquetting presses are available in various formats and filling variants to suit specific operational requirements. Depending on the required size of the press, throughputs may vary significantly between <15 and <5000 kg/h of aluminium. Depending on the size of the press, required driving power varies between 15 and 240 kW (Figure 4.21).

Figure 4.21. Technical data Arno Brik presses (Source: ATM, 2011)

technical data

		2 Columns			3 Columns			
	Arno® Brik	5	7	10	12	15	18	22
Briquette diameter	mm	50	70	105	125	140	180	210
	[in]	[2]	[3]	[4]	[5]	[6]	[7]	[9]
Briquette diameter max.	mm	70	90	120	135	150	195	250
	[in]	[2.8]	[3.5]	[4.7]	[5.3]	[5.9]	[7.7]	[9.3]
Power Main cylinder	kN	760	1,400	2,900	4,000	5,200	8,500	12,500
Briquette density steel, cast iron	kg/dm³	<5.5	<5.5	<5.5	<5.5	<5.5	<5.5	<5.5
Briquette density aluminium	kg/dm³	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4
Briquette density brass, copper	kg/dm³	<7.0	<7.0	<7.0	<7.0	<7,0	<7.0	<7.0
Capacity* steel, cast iron	t/h	<0.3	<0.5	<1.5	<2.5	<4.5	<7.5	<12.0
Capacity* aluminium	t/h	<0.15	<0.25	<0.6	<1.1	<2.2	<3.5	<5.0
Capacity* brass, copper	t/h	<0.4	<0.6	<2.0	<3.0	<6.0	<8.0	<14.0
Cycle time standard performance	s	10	10	10	10	10	10	10
Driving power standard	kW	15	22	60	90	120	180	240
Driving power increased	kW	-	30	-	-	-	-	-
Footprint	m x m	3.0x2.0	3.5x1.8	4.3x3.6	4.5x5.0	5.0x8.0	6.5x8.5	7.0x9.0
	[ft]	[10x7]	[12x6]	[14x12]	[15x16]	[16x26]	[21x28]	[23x30]

*depends on material

Most machines are suitable for heavy continuous operation and can be operated manually or automatically and can be integrated into fully automated production lines. Remote maintenance and system adjustments are possible.

As a precondition, it is important to sort the different waste metal streams corresponding to different alloys in order to allow high value recycling (e.g. for aluminium, above cast aluminium grade). Therefore, different types of aluminium should be kept separate. In case this is not ensured, aluminium chips will end in the casting industry (low value).

The length of the briquette may vary within the given parameters and the choice of the briquette format depends on the required throughput, as well as the quality of the source material and its bulk density. Briquettes can be produced in various sizes e.g. 50 to around 200mm and densities e.g. 2.4 kg/dm^3 in case of aluminium (Figure 3).

For instance, the company *Mayfran* provides various custom solutions for scrap and coolant management and material handling in metalworking, recycling, solid waste processing, and other applications. Examples of successful applications in the metal sector are for instance at GKN, a company producing aircraft wing rib sections using 3 5-axis machining centres with flood coolant. The company needs to separate chips and coolant to meet increasingly challenging regulations and maximize value on aluminium alloy scrap. Pneumatic steel belt chip conveyors are installed to collect chips and feed wringers, which return coolant for filtration. Two pneumatic blowing-based conveyors transfer chips to a bunker silo for further processing. The main benefits reported are increased scrap value and reduced coolant consumption through local recycling as well as reduced costs for transportation of chips. Other possible areas of application are for instance in matching wheelsets for rail cars (i.e. Hegenscheidt MFD), manufacture of gearboxes (i.e. Hansen Transmission), (Mayfran, 2009).

Separation of metal residues

The pre-treatment of the metal residues (scrap) is properly designed for the removal of the impurities and other undesirable substances. This can be achieved very efficiently by various methods e.g. air classification, shredding, magnetic or density separation etc.

This sector is already very well developed and there are available in the market several providers of metals separators' machines with high separation efficiency rates.

Applicability

This BEMP is broadly applicable to all types of companies, including SMEs. As a general rule, the volume of the material working residues must be significant to ensure economic feasibility. For this reason, the applicability may be limited to small product series.

Separation of metal residues is usually implemented by recyclers and re-smelters at later stage and not at the manufacturing sites. However, manufacturers can consider the installation of an on-site metal separation line based on the production series and the scale of economies.

Briquetting machines can be used for heavy and continuous operation; they can be operated automatically or manually and can also be integrated in automated production lines.

In certain cases, e.g. stringy, tangled swarf pre-processing might be required prior to the briquetter e.g. conveyor/separator, shredding or crushing.

Briquetting machines are available in various sizes to fit the exact customers' needs. The machines can be applied for a wide range of scrap metals including copper, aluminium, brass, cast iron, grinding swarf, steel, bronze, magnesium and titanium.

Depending on the required capacity and allowable downtimes, a briquetting machine could be used to process different metals. However, cleaning intervals must be planned to avoid contamination between streams.

Economics

Typical payback time for the investment in new purchased briquetting machines is reported to be around 6 to 24 months (e.g. when purchasing grinding oil at approximately 2€/l). However, this is heavily dependent on the production series and on the volume of the material working residues.

General costs for operation and maintenance are expected to be comparably low as most machines can operate fully automatically. If the feeding of machines needs to be done manually, it is expected that this can be done by one employee in a rather short time frame.

Some companies offer briquetting equipment and coolant filtration / recycling units for rental as part of a waste management package, without the need for a capital investment by manufacturers of fabricated metal products.

Further, numerous economic benefits are associated with the implementation of this BEMP. Among the main financial benefits are:

- Savings on new oil purchases
- Valorisation of waste stream (resale value of aluminium briquettes); Increasing resale value due to the briquette / puck form of aluminium (e.g. facilitated and more defined feeding of the metal into the melting furnace and low burn-off, thus increase in yield of valuable metals in the melting process of up to 10 %).
- Increasing transparency (i.e. no deductions for moisture or oil content; payment according to the exact weight of briquettes)
- Reducing / eliminating of waste disposal fees for emulsion disposal and reduced costs for new cutting emulsion / oils to be purchased
- Reduced logistical costs of swarf storage, handling and transportation (i.e. recycling of greater amounts of scrap per load with easy-to-transport briquettes)
- Reclaim valuable floor space (can be for instance converted into revenue-producing manufacturing areas)

Driving force for implementation

The most important driving forces for companies of the sector are summarised below:

- Reduction of virgin material use and reduction of waste generation as well as reduction of energy input required to produce virgin materials
- Volume reduction (after briquetting the density is higher by the factor of 5 than the bulk density of the swarf) and therefore also reduced energy consumption and carbon footprint (i.e. fewer collection rounds required)
- Reduced health and safety hazards for employees (lower dust exposure although noise emissions might increase)
- Lowering of fire and explosion risks
- Clean and safe workplace (e.g. due to improved handling)
- Compacting aluminium chips results in lower oxidation losses when the aluminium is recycled which is a positive downstream impact
- Economic benefits from avoidance of purchasing oil and recovering it instead

Reference organizations

Hansgrohe SE, a manufacturer of valves, taps etc.

Schäffler AG, a manufacturer of components mostly for the automotive sector e.g. gears

Reference literature

ATM, 2011. Briquetting press with filling variants

http://www.atm-recyclingsystems.com/fileadmin/download/PR/201110_briquetting_press_-_Recycling_International.pdf

ATM, 2013. Briquetting of oil-containing metal chips. http://www.atm-recyclingsystems.com/fileadmin/download/PR/201304_Brikettierung_Metallspaene_-_ATrecovery.pdf

Mayfran, 2009. Application profiles by industry. last accessed on 14th Septermber 2017. http://www.mayfran.com/resources/application-profiles-by-industry.html

Schaeffler AG, 2017. Personal communication. 17th August 2017.

Schön, J & Dahmen, N & Dinjus, E. (2001). Deoiling of metal cutting residues. 48. 32-39

4.6 Multi-directional forging

<table>
<tr><td colspan="6">SUMMARY OVERVIEW
When forging complex products with a high variation in cross-section, it is BEMP to apply multi-directional forging. This practice reduces significantly the formation of flash by applying pressure in different directions in the piece under fabrication, resulting in less material needing to be removed by machining afterwards.</td></tr>
<tr><td colspan="6">Relevant stages</td></tr>
<tr><td colspan="2">Cross cutting</td><td colspan="2">Optimisation of utilities</td><td colspan="2">Manufacturing</td></tr>
<tr><td colspan="6">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td></tr>
<tr><td colspan="6">Environmental performance indicators</td></tr>
<tr><td colspan="6">- Percentage of generated flash per manufactured part (%)
- Total energy required for the forging process (energy input for forging kWh / kg finished product or manufactured part)
- Resource efficiency (kg finished product or manufactured part / kg of material input)</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="4">This BEMP is broadly applicable to all types of companies in this sector, including SMEs. It is especially suitable for complexly formed components and niche products, and for companies with large production series. Multi-directional forging can be applied to a wide variety of materials (aluminium, copper, magnesium, titanium).

However, the applicability of this BEMP may be limited due to the need of purchasing special forging tools and technical knowledge, which result in high investment cost.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="4">The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement in, at least, the following indicators:
- energy use per manufactured product
- resources efficiency
- consumption of metal working fluids[58] per manufactured product</td></tr>
<tr><td colspan="2">Related BEMPs</td><td colspan="4">N/A</td></tr>
</table>

Description

By forging complex products with a high variation in cross-section, a significant amount of material usually ends up as flash. In the standard forging process, material is formed by pressure from above, so that the deformed material can "escape" to each side to form

[58] N.B. Metal working fluids consist of oils, oil-water emulsions, pastes and gases. Therefore, it can be of either solid, liquid or gas form, influencing thus the type and the equipment needed for their application and eventually the metrics used in the benchmark to monitor improvement in the environmental performance of this aspect.

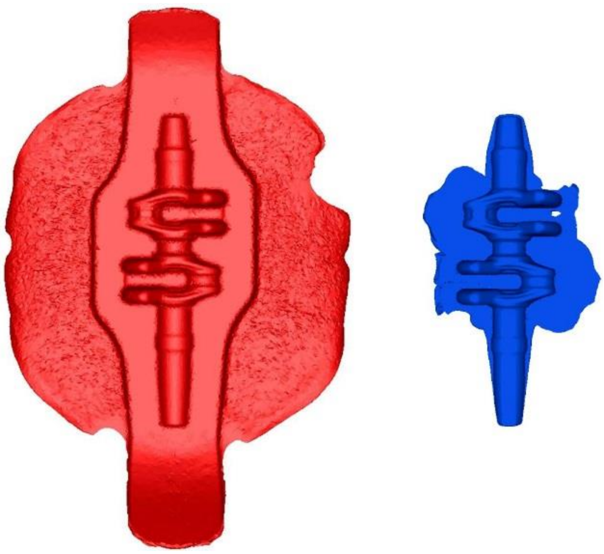
a large flash. For complex geometries, more than 40% of the material can end up in the flash, which must be removed by machining in the finishing steps.

A recently developed "flash free" and multi-directional forging concept significantly reduces the formation of flash by applying pressure in different directions. This technique can be applied to all forgeable metals, including steels and non-ferrous alloys (aluminium, copper, magnesium, titanium). The process needs a rethinking of the complete forging sequence and makes use of dedicated forging tools. To compensate for the extra effort and cost associated with the tools, multidirectional forging is especially suited for:

- Complexly formed components that have a large potential reduction of flash formation;
- Production of larger series (magnitude 1000s).

Some examples include crankshafts (Figure 4.22), connecting rods, worm wheels, trunnions and handles.

Figure 4.22. The multi-directionally forged crankshaft (right) compared with a conventionally forged one (left); significantly lower flash percentage: (IPH-Hannover, 2014)



To implement flash free multi-directional forging, companies can take the following steps:

(1) Development and simulation of the process steps

In this step, the new forging concept, consisting of a sequence of (typically 4) forging steps, is developed. A thorough knowledge of the relevant forging technologies as well as the product that will be fabricated is needed to select the optimal forging concept. Eventually, external expertise can be brought in. Usually, this step also requires some experimental tests. Complementary to testing, it is highly advisable to model / simulate the forging steps, using appropriate Finite Element Modelling (FEM) method. This gives valuable information about the quality of the (intermediate and final) forging and helps to select optimal process parameters without excessive numbers of physical experiments.

(2) Implementation of the forging sequence and forging tests in industrial environment

In this step, the practical implementation of the multi-directional forging concept is worked out. This includes:

- Identification of the machines that will be used;
- Development of the forging tools (based on the findings of the previous step) including forging tools design and heating concepts.

(3) Validation of the process sequence and the resulting materials and component properties

In this final step, before industrial production, a test run is performed to validate the new multi-directional forging concept. The following questions must be answered before the industrial production:
- Do the forgings have the required properties?
- Is the quality consistent and reproducible?

Possibly, some minor modifications or "fine-tuning" is needed in this step that will ensure the quality of the final products and will validate the right choices/decisions in the previous steps.

Figure 4.23. **Examples of components that can benefit from "flash free" and multidirectional forging (Hatebur, 2015)**

Achieved environmental benefits

Direct effects are the reduced formation of flash, which leads to a reduction of material needed for production of work pieces. The actual material savings will depend on the specific material used and geometry of the work piece.

In the case of cylinder crankshaft forging, elaborated in the REForCH project, flash formation was reduced significantly from 54% to 7%, which corresponds to a raw materials reduction from 10.8 to 7 kg needed to make the same component (Forging magazine, 2014).

It results also in a reduction of waste, and the process reduces the need of finishing machining operations. The latter leads to a reduction in energy use (both related to the machining itself and the embodied energy in the flash) and reduces the consumption of cooling lubrication fluids for the finishing machines.

In order to compensate the extra heat loss during the multi-directional forging compared to standard forging, the work piece is heated additionally before this step using for instance induction heating. Even though additional energy is needed, the total energy use of the forging process is about 20% lower compared to conventional forging. This is mainly due to the reduction of the total weight of the material that must be heated before forging (REForCH, 2014).

Finally, an additional environmental benefit is that upstream in the value chain, less materials must be produced, which leads to a reduction of resource use and emissions.

Appropriate environmental performance indicators

Since multi-directional forging leads to material and energy savings, the following environmental indicators are considered appropriate:

- Percentage of generated flash per manufactured part (%)
- Total energy required for the forging process (energy input for the forging process kWh / kg finished product or manufactured part)
- Resource efficiency (kg finished product or manufactured part / kg of material input)

The first indicator measures the amount of flash generated during the forging process; it is calculated by dividing the amount (weight) of flash generated by the amount (weight) of the processed material. The second indicator represents the energy required for the forging process; energy used in the forging divided by the decided by the company functional output unit. The third one measures the resource efficiency of the forging process, which is the decided by the company functional output unit, divided by the amount of material inserted for processing.

Cross-media effects

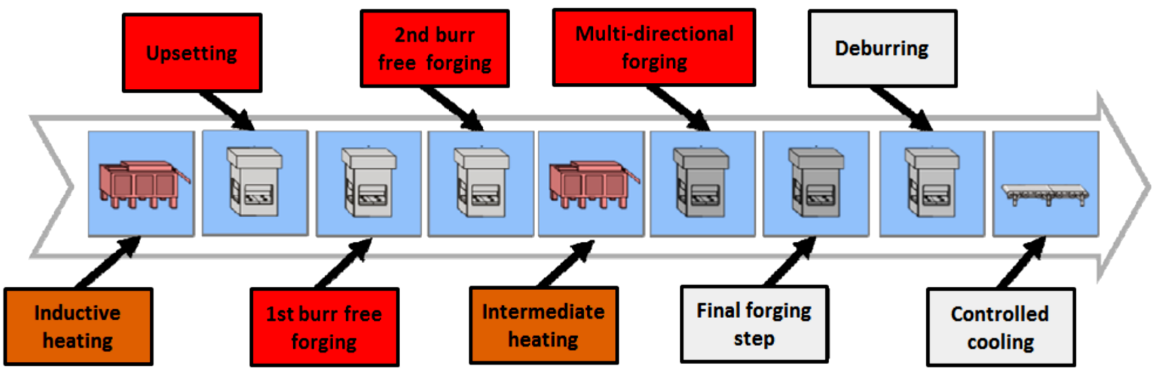
Although the forging concept and sequence is changed, there is no need to use different or more chemicals compared to traditional forging. There are no cross-media effects due to the use of this technology.

Operational data

The "flash free" multi-directional forging operation consists of multiple steps (

Figure 4.24). The multi-directional forging is typically applied at the end phase of the forging sequence (for instance in the case of the crankshaft, in step 4 out of 5 forging operations).

Figure 4.24. Example of a "flash free" multi-directional forging sequence of a complex steel part (e.g. crankshaft), (IPH-Hannover, 2015)

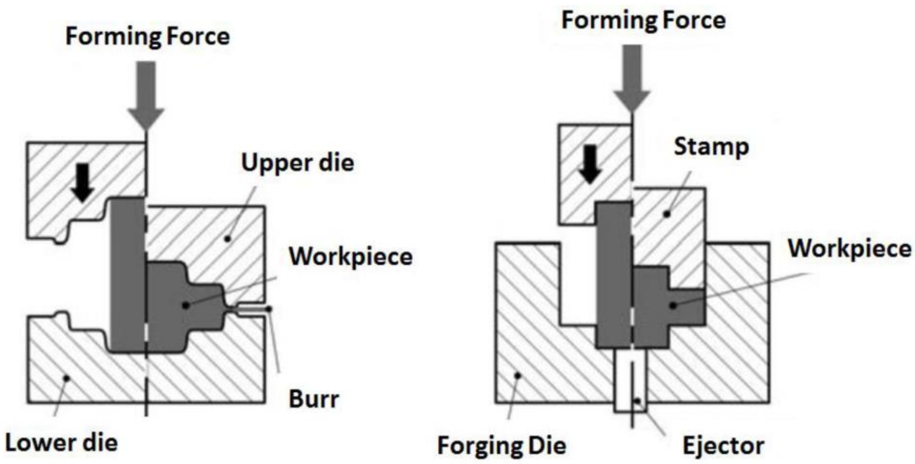


For the work piece, this corresponds to intermediate parts as shown below in Figure 4.25.

Figure 4.25. **Workpiece stages during the five forging steps that are needed for the finished crankshaft. The fourth step takes place with the multidirectional tool (IPH-Hannover, 2014)**

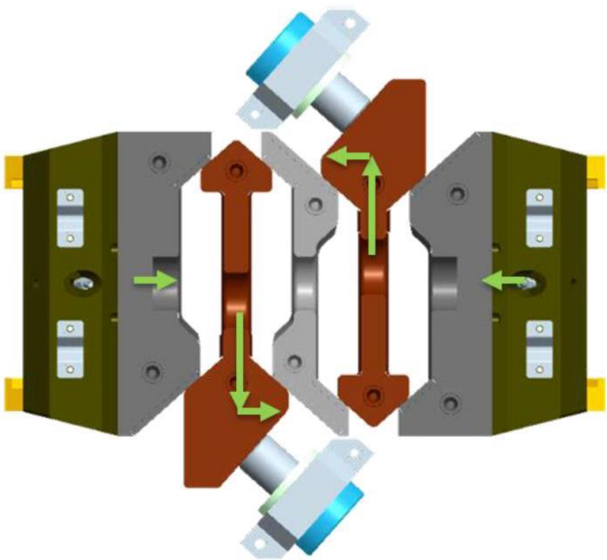
In order to minimise the formation of flash, the complete forging concept, including the forging tools for all the different steps have to be adapted. In the initial forging steps, traditional forging set-up is replaced by "flash free" as shown in Figure 4.26.

Figure 4.26. The adapted forging tools and the associated material flow in the "flash free" forging concept (right) leads to significant reduction or elimination of flash formation in comparison with the traditional set-up (left) (IPH-Hannover, 2015)



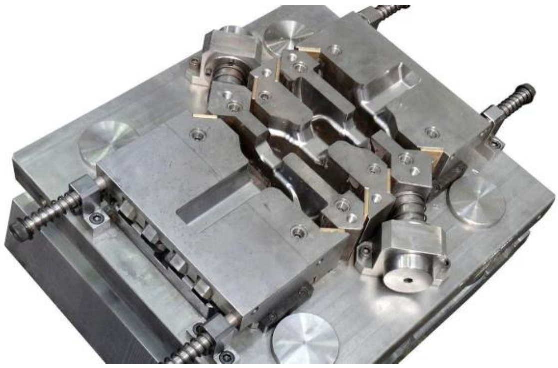
In addition, the multidirectional forging step needs a specially developed forging tool. This has to support proper mass flow in multiple directions during the forging step, and at the same time limit the occurrence of flash. Whereas traditional forging tools only move in one dimension at a time, multi-directional forming tools allow for simultaneous movement of forming parts in multiple directions (Figure 4.27). This ensures high quality and flawless forging parts with the right microstructure and material properties.

Figure 4.27. CAD model of a multi-directional forging tool for the forging of a crankshaft (the arrows indicate multiple directions of moving tool parts), (IPH-Hannover, 2015)



The tool design must be tailored to the required material flow. Finite element simulations allow predicting mass flow during forging based on tool geometry, material properties and process parameters. They are a performant aid to optimize the tool geometry. The tool concept must also take into account the pressures and temperature distribution at all stages of the forging process. Application of well-chosen tool materials, coatings and/or lubricants can enhance tool durability (Figure 4.28).

Figure 4.28. Example of a multi-directional forging tool, which not only presses metal into the form from above, but also simultaneously from the sides (IPH-Hannover, 2014)



This tool can typically be used in normal eccentric presses to produce work pieces.

Applicability

This BEMP is broadly applicable by all companies of the sector, regardless their size. It can be applied to a wide variety of materials (aluminium, copper, magnesium, titanium) and product geometries. The need of dedicated forging tools, results in higher investment cost and makes the BEMP more suitable for large companies and for the fabrication of larger series of complexly formed components.

Economics

Multi-directional forging represents an innovative possibility to reduce production costs and to produce forged components more efficiently. Furthermore, energy costs in production can be reduced, because less material needs to be heated *(IPH-Hannover, 2015*). Table 4.6 shows a fictional sample calculation, clarifying the saving potential of multi-directional forging:

Table 4.6. Fictional sample calculation, clarifying the saving potential of multi-directional forging (IPH-Hannover, 2015)

Components per year: 1.000.000	conventional forging	multi-directional forging
forging tonnage	13.500 t	10.000 t
material costs	10.800.000 €	8.000.000 €
energy costs	600.000 €	444.000 €
sum of costs	11.400.000 €	8.444.000 €
savings	**2.956.000 €**	
assumptions: component weight: 10 kg/ part, material costs: 0.80 €/ kg, energy costs: 0.12 €/ kWh, percentage of forging: 35 %		

Material costs usually account for 50% of the total production cost of the pieces, and energy about 5%. The reduction of material (minus 45%) and energy (minus 20%) consumption consequently leads to a reduction of the production cost of about 25% per piece. Of course, part of this cost savings are offset by the development, production and validation of the forging tool, so net savings are very much depending on the production volume (REForCH, 2014). In view of future economic and price developments, the attractiveness of the multi-directional forging will gain in importance in the coming decades (IPH-Hannover, 2015).

Driving force for implementation

When implementing multi-directional forging, new specially developed forging tools have to be purchased, which are usually more complex and expensive. Considering that in the forging industry, the purchasing price of the tool is only a small part, but the material costs however, account for more than 50% of the production costs, this technology significantly reduces production costs (IPH-Hannover, 2015). This leads to cost savings from the moment that the start-up costs (development, tooling) are leveraged over enough pieces. Consequently, both economic and environmental drivers are applicable.

Reference organisations

Omtas Otomotiv Transmisyon Aksami (based in Turkey) – Omtas participated in the consortium of a 7th framework project, called REForCH and developed a two-cylinder crankshaft thanks to multidirectional forging. Producer of engine parts: http://omtas.com/

IPH - Institut für Integrierte Produktion Hannover GmbH (spin-off of the University of Hannover): http://www.iph-hannover.de/de

PCC (UK) –Wyman-Gordon's Livingston facility in UK, supplier of forged products to the aerospace and energy sectors, http://www.pccforgedproducts.com.

Ellwood crankshaft group (US) – producer of metal parts for marine, locomotive, oil & gas companies, power generation and mechanical presses has two multi-directional forging presses operation units. http://www.ellwoodcrankshaftgroup.com/Vertical-Integration/Forging.aspx.

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4.7 Hybrid machining as a method to reduce energy use

<table>
<tr><td colspan="6">SUMMARY OVERVIEW
BEMP is for fabricated metal product manufacturers to use hybrid machining if this allows a significant decrease in the total energy needs for machining per single part/product/component by combining two or more different manufacturing processes into a new setup exploiting synergistically the advantages of each individual process.
The combination of the various manufacturing processes e.g. milling, drilling can enable more freedom in the design and fabrication of parts, products, components when compared to the use of conventional machining technologies.</td></tr>
<tr><td colspan="6">Relevant stages</td></tr>
<tr><td colspan="2">Cross cutting</td><td colspan="2">Optimisation of utilities</td><td colspan="2">Manufacturing</td></tr>
<tr><td colspan="6">Main environmental benefits</td></tr>
<tr><td>Resource efficiency</td><td>Water</td><td>Waste</td><td>Emissions to air</td><td>Energy and climate change</td><td>Biodiversity</td></tr>
<tr><td colspan="6">Environmental performance indicators</td></tr>
<tr><td colspan="6">- Energy use (kWh / kg finished product or manufactured part)
- Resource efficiency (kg finished product or manufactured part / kg of material input)</td></tr>
<tr><td colspan="2">Applicability</td><td colspan="4">Hybrid machining is broadly applicable to all types of companies in this sector. It is especially suitable for manufacturing sites that have new machines. Hybrid machining is very relevant for the manufacturing of parts/products/components with complex geometries.
The combination of relatively high investment costs and lack of in-house specific technical knowledge/capacity required to implement this BEMP may limit its applicability, especially in SMEs.</td></tr>
<tr><td colspan="2">Benchmarks of excellence</td><td colspan="4">The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement in, at least, the following indicators:
- energy use per manufactured product
- resource efficiency
- consumption of metal working fluids[59] per manufactured product</td></tr>
<tr><td colspan="2">Related BEMPs</td><td colspan="4">N/A</td></tr>
</table>

Description

Hybrid machining combines two or more manufacturing processes into a new combined setup. The combined setup has the advantages of each of the individual manufacturing technologies, such as accuracy, surface quality etc. and at the same time reduces the adverse effects that the constituent processes produce when they are individually applied. Moreover, the application of hybrid machining techniques can extend the technological process limits by combining additional sources of energy and conventional

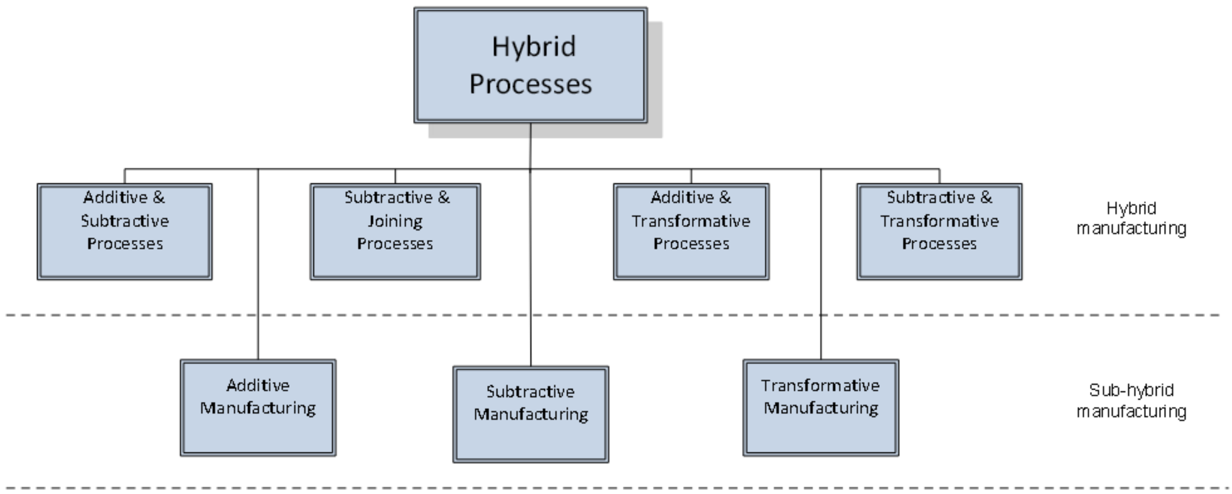
[59] N.B. Metal working fluids consist of oils, oil-water emulsions, pastes and gases. Therefore, it can be of either solid, liquid or gas form, influencing thus the type and the equipment needed for their application and eventually the metrics used in the benchmark to monitor improvement in the environmental performance of this aspect.

existing machining processes (Fraunhofer, 2016). Overall, the application of this technique can result in lower total energy requirement for machining per single part and can also shorten the process chain since it reduces the thermo-load and cutting forces (Zhu et al., 2013; Neugebauer et al., 2012).

The combination of various manufacturing processes (e.g. milling, drilling, grinding, turning) enables more freedom in the design of parts, components and products, especially for those with complex geometries, which would not be feasible through the use of conventional manufacturing technologies.

Hybrid machining consists typically of the processes illustrated in Figure 4.29. These can be classified into several major categories, based upon the combination of machining technologies. For instance, subtractive processes are e.g. milling, turning and drilling, while additive processes can be Selective Laser Sintering (SLS), Selective Laser Melting (SLM) and Laser Cladding. Removing processes include laser softening, electrical discharge machining (EDM) as well as electro-chemical dissolution (ECD). In practice, a mechanical conventional single cutting or media assisted (MA) action process can for example be combined with the respective machining phases of electro discharge (ED) in electro discharge machining (EDM) or ECD into Electro Chemical Machining (ECM). However, when the combination of the different manufacturing processes are from the same manufacturing technology, then this is called sub-hybrid manufacturing process (Zhu et al., 2013).

Figure 4.29. **Hybrid machining process classification (Zhu et al. 2013)**



To detect possibilities for hybrid machining, entire processes must be broken down to their single steps and their functional requirements for each step are listed. Based on that, the most suitable technology for each process step can be chosen, taking into consideration the energy use as well as other relevant parameters (geometry, material type and its properties etc.). Additionally, this breakdown helps the manufacturers to understand the nature of each process and also the motivation for its application (Table 4.7). Often, this will result in one or more roughing operations applying a fast and energy efficient technology, in combination with a finishing operation that will be slower and more energy consuming. The outcome is a process divided into more working steps but with lower total energy use compared to the situation in which the energy intensive finishing technology is applied exclusively.

Table 4.7. Examples of hybrid machining processes

Principle	Process Variants	Motivation for Application
Vibration-superimposed machining	drilling turning grinding	improvement of chip breaking
	EDM ECM	improvement of quality, productivity
Media-superimposed machining	high pressure cooling	improvement of chip breaking
	cryogenic cooling	increase in material removal rate
Machining with superimposed movement of the axis	scissors kinematics	increase in dynamics in die and mould making
	out-of-round machining by adaptronic form honing and boring	improvement of the operating properties of engines

Sources: Neugebauer et al., 2012; Fraunhofer, 2014

Designers and engineers working in the metal processing sector usually have multiple choices when it comes to machining technology. For example, hybrid lathes, which combine laser softening with turning, allow faster and more energy efficient material removal rates compared to conventional turning or laser ablation.

Overall, the combinations of the different manufacturing processes aim to enhance the advantages of the individual manufacturing technologies and to reduce or avoid potential disadvantages from their application.

Achieved environmental benefits

Hybrid machining leads to significant advantages:

- Lower lead times due to faster machining processes and therefore also lower energy use and related CO_2 emissions;
- Reduced thermo-mechanical load and cutting forces lead to more efficient use of tools and less amount of consumables e.g. lubricoolants;
- Overall lower operating expenditure.

Due to the synergies between interacting processes in hybrid machining, the overall machining process is more efficient than the sum of its individual parts. This efficiency is expressed in machining time, spindle power, electrode consumption, tool wear, cooling water- or compressed air consumption.

Appropriate environmental performance indicators

The most appropriate environmental performance indicators for this BEMP are the following:

- Energy use (kWh / kg finished product or manufactured part)
- Resource efficiency (kg finished product or manufactured part / kg of material inserted for processing)

Cross media effects

The combinations of the different processes does not necessarily mean that all productivity measures are improved. For instance, one combination may only aim an improved chip breakage, while other combination may improve the machinability of the fabrication of a certain product/part/component (Lauwers et al., 2014).

Hybrid machining initially requires bigger investments in hardware and has also an influence on the environmental impact due to the production of these new machines. In addition, extra cooling water or compressed air circuits might be required for hybrid machining processes, offsetting the achieved energy gains. Care should be taken that these factors are taken into consideration when applying hybrid manufacturing.

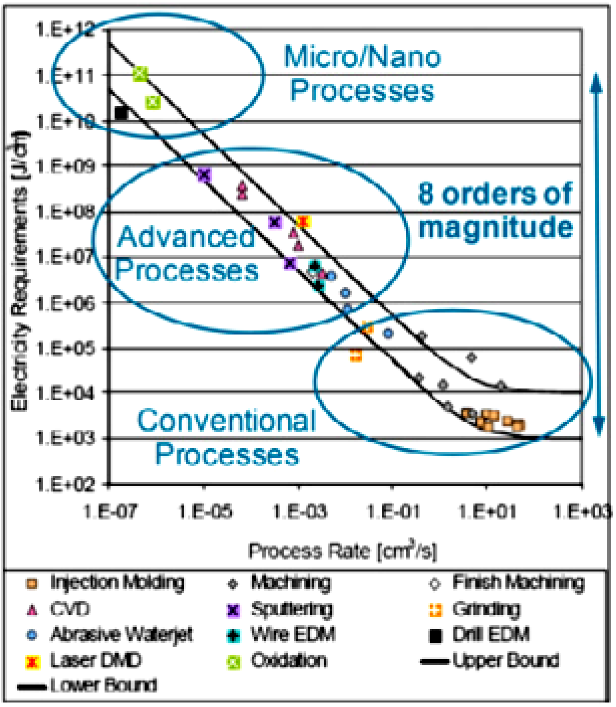
A major cross-media effect is the potential waste generation and overall resource efficiency, in the case a company purchases new equipment and thus needs to dispose of the old machines. In order to reduce the environmental impact, used equipment should be reused or recycled whenever possible.

The highest benefits can be achieved when the different processes are installed on the same machining platform. In the case two separate platforms are required the investment cost might offset the benefits (Zhu et al., 2013).

Operational data

Parameters such as geometry of the component, technical specification, material type and properties and the lot size need to be carefully assessed before any choice on the type of processes. In fact, the choice for processes can significantly influence the energy use and the material use for the manufacturing of a part (Figure 4.30).

Figure 4.30. Electrical energy requirement for different processes (Gutowski et al., 2006)



Each processing technology has a certain process speed/velocity (cm^3/s) and specific energy requirements (J/cm^3) that together define the total energy use over time and the material use. Functional part requirements such as surface quality, geometric constraints and material properties often limit the applicability of high-speed and low-energy processes such as milling and turning. Engineers responsible for supervising the processes often choose one particular manufacturing technology based upon the functional requirements of the final product.

Applicability

This BEMP is broadly applicable for all sizes of manufacturing companies. It is more suitable for new machines and/for new-built manufacturing sites. The entire carried out processes and machining operations need to be carefully analysed including all single steps and their functional requirements. Based on the outcome of the assessment, manufacturers can opt for the most suitable hybrid machining technology, considering the energy use as well as other relevant parameters e.g. geometry, material type and its properties. In general, hybrid machining technologies can be applied to almost all processes as long as the combination of different manufacturing technologies offers a substantial increase in performance and/or capabilities (Le et al., 2017). However, the combination does not necessarily imply that all productivity parameters will be enhanced. For instance, one combination may aim for chip breakage, while another can aim for the machinability of the part (Lauwers et al., 2014). In any case, the need for in-house specific technical knowledge/expertise is essential for the implementation of the BEMP, which may constitute an important barrier at the same time, especially for SMEs.

Hybrid machining technologies of deposition machining are not feasible for powder-bed fusion processes as they would damage the non-processed powders, making it impossible to proceed with subsequent layers.

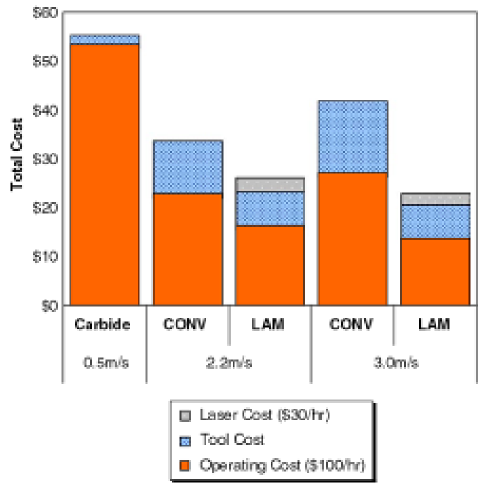
Hybrid machining technologies is suitable for the machining of parts/components made of tough-to-process alloys. This results in shorter machining times and implementation of the machining operations with precision tolerance and excellent surface finish.

The maintenance of hybrid machines, especially when integrating blown powder laser Directed Energy Deposition (so called DED) into a machine tool, the use of coolants and maintenance of the working envelope of the machine tool may limit the applicability of this BEMP. Special attention has to be paid to the application of coolants during machining because processing heads are installed in the same envelope. The optics might get contaminated. Moreover, the off-spindle centreline approach demands relevant stroke of the machine and thus restricts the additive stroke significantly (Lorenz et al., 2015).

Economics

A substantial reduction in operating costs is expected due to lower lead times, less consumables, more efficient use of coolant/dielectric and related lower energy use. However, additional investments are expected for the machine itself and/or additional infrastructure. Moreover, maintenance costs may be higher. An example for laser assisted machining (LAM) is represented in Figure 4.31. Conventional turning with carbide inserts is compared to conventional turning with ceramic inserts, both with and without the assistance of a laser that softens the material prior to chip formation. The result is a drastic reduction by 50% of the operating costs for the machining of 1m of Inconel 718 using ceramic inserts compared to classical machining without laser assistance (Anderson et al. 2006).

Figure 4.31. Conventional Machining vs Laser Assisted Machining (LAM) (Anderson et al. 2006)



Driving force for implementation

The main driving forces for implementation are the lower lead times and the lower energy use for implementing hybrid machining in the metal fabrication sector. Moreover, the production of parts/products with complex geometries, which require combination of different machining processes is an additional driving force for implementation of this BEMP.

Reference organisations

DMG Mori. DMG MORI integrates the additive manufacturing into a high-tech 5-axis milling machine. This hybrid-solution combines the flexibility of the laser metal deposition process with the precision of the cutting process and therewith allows additive manufacturing in milling quality. http://en.dmgmori.com

HAMUEL Maschinenbau GmbH & Co. A technology provider delivering hybrid machining solutions for mechanical engineering, turn-milling machine and mineral casting. The switching between milling, cladding and probing, is automated and thus stand by and related energy use are reduced, www.hamuel.de.

Yamazaki Mazak manufactures not only advanced machine tools such as multi-tasking centres, CNC turning centres, machining centres and laser processing machines but also automation to support global manufacturing by providing exceptional productivity and versatility (http://www.mazak.eu).

The Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University stands for successful and forward-thinking research and innovation in the area of production engineering. Their system combines the use of a hybrid micro-milling/micro-EDM system. The roughing operation is performed by micro-milling, which has a lower specific energy use compared to micro-EDM. http://www.wzl.rwth-aachen.de.

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Gupta, 2015 – Hybrid Machining Processes: Perspectives on machining and finishing. By Kapil Gupta, Neelesh Kumar Jain, R.F. Laubscher, 2015

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K. A. Lorenz, J.B. Jones, D. I Wimpenny and M.R. Jackson, (2015), A review of hybrid manufacturing. Solid Freeform Fabrication Conference Proceedings. Vol. 53.

Lauwers B., Klocke F., Klink A., Tekkaya A.E., Neugebauer R., Mcintosh Don (2014), Hybrid processes in manufacturing, CIRP Annals, 63(2), 561-583.

4.8 Use of predictive control for paint booth HVAC management

SUMMARY OVERVIEW
BEMP is to minimise the energy use of the HVAC for pain booths by implementing a predictive control system, based on feedback and forward control, operating on a window of values. Such system allows keeping constant the speed at which the paint dries without necessarily maintaining constant the temperature and humidity levels in the paint booth, as is the case in conventional control systems. The working principle is keeping constant only the difference between the limit to how much vapour can be absorbed by the air (which varies with temperature) and the amount of water vapour already in the air.

Relevant stages		
Cross cutting	Optimisation of utilities	**Manufacturing**

Main environmental benefits					
Resource efficiency	**Water**	Waste	**Emissions to air**	**Energy and climate change**	Biodiversity

Environmental performance indicators	
- Energy use for painting (kWh/ m² of surface coated/painted)	
Applicability	This BEMP is suitable for companies with large series of production, large paint booths and with multiple paint booths. The full and effective implementation of the BEMP requires: • qualified employees with profound knowledge of the paint drying process and of paint quality control; • maintenance of the effectiveness of the installation; • reliable and continuous data monitoring (sensors, measuring, etc.) and automation systems in place (on-site). The fulfilment of the increased above mentioned requirements in combination with the lack of in-house technical knowledge and high investment costs constitute a barrier to its implementation, especially for SMEs.
Benchmarks of excellence	The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement in, at least, the following indicators: - energy use per manufactured product - resources efficiency - consumption of metal working fluids[60] per manufactured product
Related BEMPs	2.3, 2.7

Description

BEMP 3.1 (Efficient ventilation) describes different steps for optimising ventilation systems. One of the approaches described is controlling ventilation according to the

[60] N.B. Metal working fluids consist of oils, oil-water emulsions, pastes and gases. Therefore, it can be of either solid, liquid or gas form, influencing thus the type and the equipment needed for their application and eventually the metrics used in the benchmark to monitor improvement in the environmental performance of this aspect.

actual needs, by means of feedback control: a central steering unit controls the ventilation valves based on data from the machines. The present BEMP focusses on the heating, ventilation and air conditioning[61] (HVAC) system used in the paint booths for fabricated metal products, which offer specific opportunities for further reductions of the environmental impact thanks to the implementation of predictive control

HVAC for paint booths is responsible for the highest share of the energy use in painting facilities. To evaporate the solvent (oil or water) in the paint, dry air is needed. Depending on the temperature of the air, there is a limit to how much water vapour it can absorb. The speed at which the paint dries depends on the difference between this limit and the amount of water vapour already in the air. This means that, even when the temperature or humidity changes, if this "difference" can be kept constant, it is possible to achieve a constant paint drying speed without necessarily maintaining constant the temperature and humidity levels, as it is the case in conventional control systems.

Using forward control on top of feedback control allows managing the optimal working conditions depending on the incoming air conditions (temperature and humidity). Controlling the evaporation rate by adjusting the humidity level depending on the ambient temperature in the paint booth means that it is no longer necessary to maintain a fixed temperature in the booth (Figure 4.32).

A predictive control system for paint booth HVAC continuously controls the maximum water vapour absorption volume by monitoring the external air conditions and making the smallest necessary adjustments to temperature and humidity inside the paint booth. The system significantly reduces energy use (Automotive manufacturing solutions, 2015).

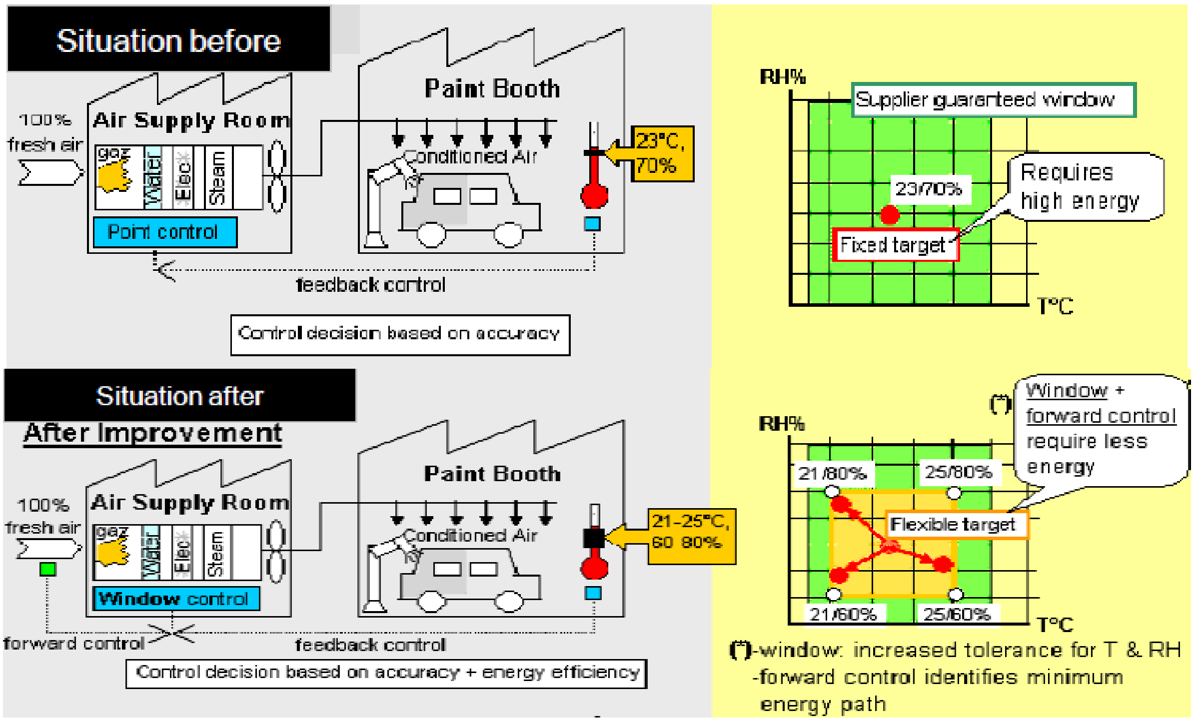
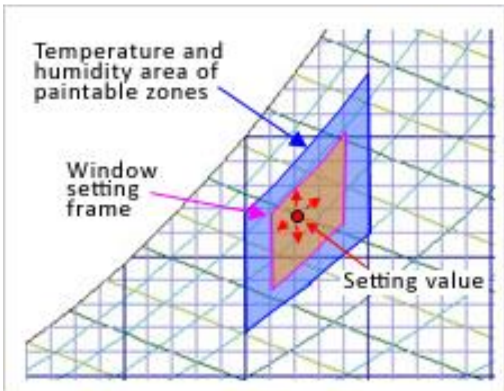


Figure 4.32. Situation before: situation of the paint booth with feedback control; Situation after: situation of the paint booth with forward and feedback control (Toyota motor manufacturing, 2015 –Personal communication at the Agoria event on automotive)

[61] The operation of this HVAC is controlled by the energy management system of the manufacturing company and can be found in the BEMP 2.3 Energy management.

A predictive control system, based on feedback and forward control, gives the best result in an HVAC system that has an increased tolerance (window of values) for temperature and humidity and selects the best energy-saving operation mode (Figure 4.33). These are called window control systems (Taikisha-group, 2015).

Figure 4.33. Control window versus control point (Taikisha-group, 2015)



Achieved environmental benefits

By implementing predictive control, less energy is needed for the conditioning of the air for the paint booth. This leads to a reduction in CO_2 emissions and other emissions due to heating and cooling. In the case shown above, Toyota could reduce CO_2 emission by 62% over 2 years. In other case (see operational data section), reductions in the energy use in the paint booth of 15-25% are reported.

Appropriate environmental performance indicators

Fabricated metal products manufacturing companies can use the following indicator to establish a baseline and/or track progress in the area of energy use in the paint booth:

- Energy use for painting (kWh/ m^2 of surface coated/painted)

Cross-media effects

No cross-media effects due to the use of this technology could be identified.

Operational data

Different companies improved their HVAC systems for paint booths by implementing some forms of predictive control. Some examples are briefly introduced in the following paragraphs:

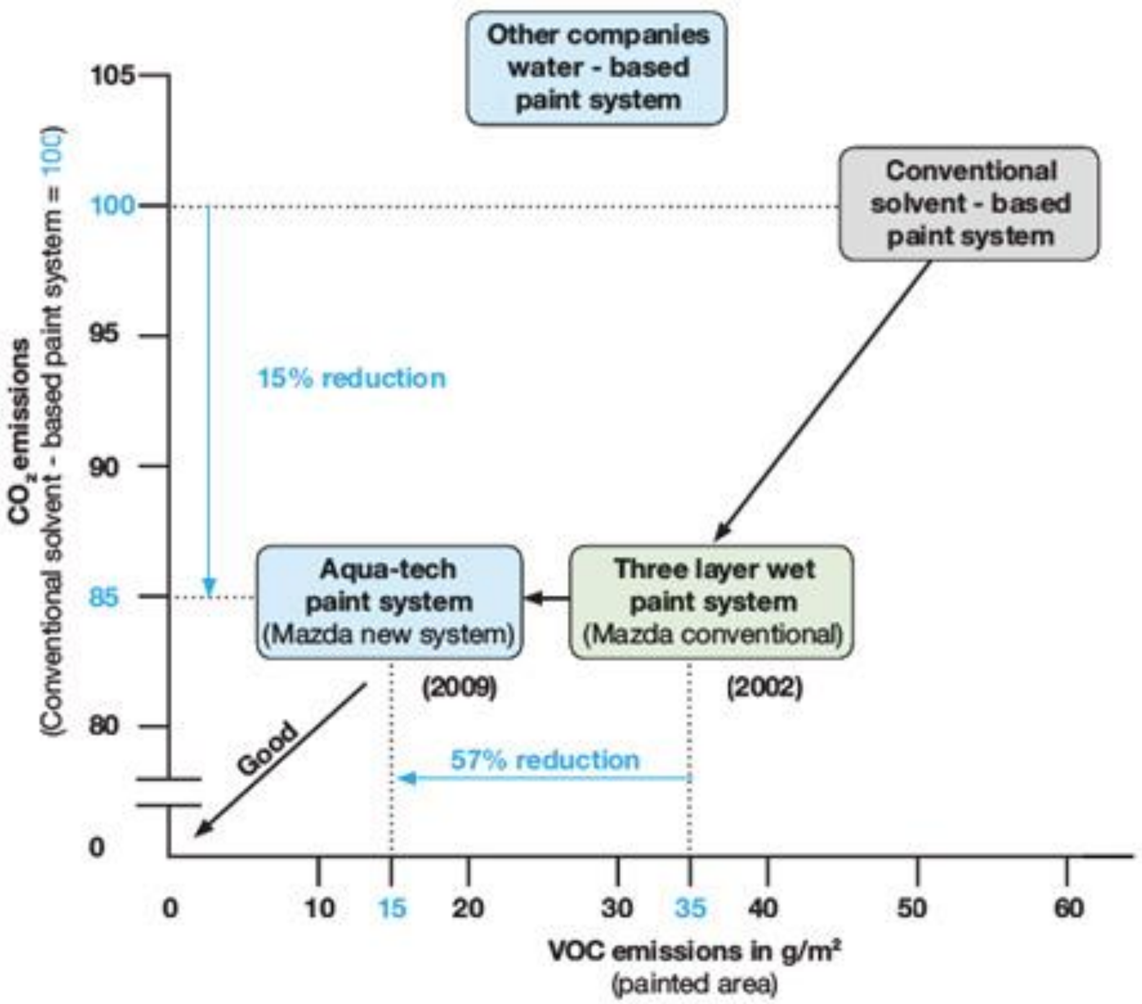
Case Study: Honda Marysfille, Ohio (USA)

Honda has developed a new air-conditioning control system that has reduced energy use by 25% in the paint booths at their assembly plant in Marysfille. This resulted in a 24% CO_2 emission reduction from the natural-gas consumption in the paint shop. This savings are due to precise control of temperature and relative humidity in the paint booths that together affect paint viscosity and thickness, which in turn influence the quality of the paint finish. The system includes a mechanism that predicts changes in temperature and relative humidity based on historical weather data for the area. In other words, it tries to stay one step ahead of changes in weather instead of reacting only after the weather conditions have changed (Kisiel, 2008).

Case study: Mazda Motor Corporation, Japan

Mazda developed a system that continuously monitors the maximum water vapour absorption volume to make the smallest necessary adjustments to temperature and humidity inside the paint booth. Together with a switch from oil based paints to water based paints, this resulted in a 15% CO_2 emission reduction. Indeed, in a conventional system the process involves raising the temperature to 80°C until the paint is sufficiently dry, and reducing it to 40°C before the clear coat can be applied. These changes can be avoided with the new system so that the water can be efficiently removed with the lowest possible energy use (Automotive manufacturing solutions, 2015).

Figure 4.34. Reduction of CO_2 and VOC by the use of water based paint and forward control of the HVAC of the paint booth, comparing to conventional oil based paint and conventional drying technology (Automotive manufacturing solutions, 2015)



Case study: Toyota motor manufacturing, UK

A comparable technology was installed at the Toyota plant in the UK and resulted in a reduction in energy use for the paint booths of 25%, corresponding to a saving of 4% of the total energy use of the site (Toyota motor manufacturing, 2015 – Personal communication at the Agoria event on automotive; Honeywell, 2009). See Figures in the Description section.

Applicability

HVAC systems with predictive control are more complex than conventional systems. They require:

- - Qualified employees with profound knowledge of the paint drying process and of paint quality control;
- - Maintenance and follow up (sensor performance, etc.) to maintain the effectiveness of the installation;
- - Strong and reliable data capturing (sensors, measuring, etc.) and automation.

To make use of the entire potential of such systems, it is important that a company is capable to handle these augmented complexities and that the degree of capacity utilisation is high.

Therefore, this BEMP is generally implemented in large paint booths using water based paints and especially by companies with multiple paint booths (even across different locations), because the investment and research costs, in terms of gathered knowledge, are relatively high. This constitutes a significant barrier for the SMEs.

Economics

The investment for upgrading the control system of the paint booth HVAC installation are paid back in a reasonable time span by the economic savings in terms of reduced energy costs. For instance, Toyota Motor Manufacturing (UK), whose case study is presented above, expects to achieve a full return on its investment in less than two years (Honeywell, 2009).

Driving force for implementation

Main driving forces for implementation are:

- Cost reduction;
- Reduction of emissions and energy use;
- Better control on the quality of the painted pieces.

Reference organisations

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Mazda Motor Corporation implemented the system for vehicle body painting at its Ujina Plant No.1, in Japan, http://www.mazda.com/

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5 Conclusions

Table 5.1 lists all the identified key environmental performance indicators for each identified BEMP along with the conditions of applicability and benchmarks of excellence where was feasible and meaningful.

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BEMPs	Key environmental performance indicators	Benchmarks of excellence
Cross - cutting measures		
2.1 Applying effective methods for environmental management	- Resource efficiency (kg finished products / kg of material input (alternatively: kg waste produced / kg input materials in case the kg finished products are not known) - Resource efficiency (kg waste produced / kg input materials) - Mapping of material flows and their environmental relevance (Y/N) - On-site energy use (kWh / kg finished product or manufactured part) - Scope 1, 2 and 3 CO2-emissions (kg CO2 equivalent / kg finished product or manufactured part) - Water use (l water / kg finished product or manufactured part)	- Management and circular economy in all strategic decisions making. - New products developments are assessed for environmental improvements.
2.2 Collaboration and communication along and across the value chain	- Percentage of goods and services (% of the total value) which are environmentally certified or with a demonstrably reduced environmental impact. - Use of by-products, residual energy or other resources from other companies (kg materials from other companies / kg total input; MJ energy recovered from other companies / MJ total energy use). - Systematic stakeholder involvement with a focus on improved environmental performance (e.g. in product design, improved supply chain environmental performance, sustainable sourcing, cooperation for improved waste management) (Y/N) - Purchase of second-hand machines or use of machinery from other companies (Y/N)- Amount of packaging waste (kg of packaging waste / kg finished product or manufactured part)	- All purchased goods and services meet environmental criteria established by the company. - Collaboration with other organisations to use energy and resources more efficiently at a systemic level. - Structural engagement of stakeholders in the development of more environmentally friendly products
2.3 Energy management	- Energy use per manufactured product (kWh / kg finished product or manufactured part) - Energy monitoring system at process level (Y/N) - Budget allocated to all energy efficiency improvements with return on investment up to five years (€/yr).	- Continuous energy monitoring at process level is implemented and drives energy efficiency improvements. - Budget is allocated to all energy efficiency improvements with return of investment up to five years.
2.4 Environmentally and	- For individual chemicals used, amount of chemical applied (kg / kg	- Regular (at least once a year) review of the

BEMPs	Key environmental performance indicators	Benchmarks of excellence
sound efficient management of chemicals	finished product or manufactured part) and its classification according to Regulation 1272/2008 (CLP Regulation) - Amount of chemical waste generated (kg / kg finished product or manufactured part)	use of chemicals to minimise their use and explore opportunities for substitution
2.5 Biodiversity management	- Number of projects collaborations with stakeholders to address biodiversity issues (no) - If located in or adjacent to protected areas: size of areas under biodiversity friendly management in comparison to total area of company sites (%) - 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, m²) - Procedure/instruments in place to analyse biodiversity related feedback from customers, stakeholders, suppliers (Y/N) - Plan for biodiversity gardening in place for premises or other areas owned, leased or managed by the company (Y/N) - Total size of restored habitats and/or areas (on-site or both on-site and off-site) to compensate for damages to biodiversity caused by the company (m²) in comparison to land used by the company (m²).	- Biodiversity action plan is developed and implemented for all relevant sites (including manufacturing sites) to protect and enhance the local biodiversity
2.6 Remanufacturing and high quality refurbishment of high value and/or large series products and components	- Percentage of saved raw material per remanufactured product (kg of material to remanufacture / kg of material for new product) - Avoided CO_2equivalent emissions (Scope 3) for remanufacturing a product instead of producing a new one (CO_2emssions remanufacturing / CO_2 emissions new product	- The company offers remanufactured/refurbished products with LCA verified environmental benefits.
2.7 Link to the relevant Reference Documents on Best Available Techniques (BREFs)	- Consideration of relevant BATs (Y/N)	- N/A
Optimisation of utilities		
3.1 Efficient ventilation	- Effective air volume extracted from the building (m³/hour, m³/shift or m³/production batch)	- Demand driven ventilation is implemented to reduce HVAC energy use.

BEMPs	Key environmental performance indicators	Benchmarks of excellence
	- Demand driven ventilation system (Y/N) - Energy use for ventilation per m³ building (m³/hour, m³/shift or m³/production batch) - Energy use to heat or to cool the air used for ventilation per m³ building (m³/hour, m³/shift or m³/production batch)	
3.2 Optimal lighting	- Use of daylight wherever possible (Y/N) - Share of the lighting controlled by sensors (motion sensors, daylight sensors) (%) - Energy use of lighting equipment (kWh/year/m² of lighted floor) - Installed lighting power (kW/m² of lighted floor) - Share of LED/low-energy light bulbs (%) - Average efficacy of luminaires throughout plant (lm/W)	N/A
3.3 Environmental optimisation of cooling systems	- Total equivalent warming impact (TEWI) of the cooling system (CO2e) - Global warming potential (GWP) of refrigerants used (CO2e) - Energy use for cooling (kWh/year; kWh/kg finished product or manufactured part) - Water use (tap water / rain water / surface water) for cooling (m³/year; m3/kg finished product or manufactured part)	N/A

BEMPs	Key environmental performance indicators	Benchmarks of excellence
3.4 Rational and efficient use of compressed air systems	- Electricity use per standard cubic meter of compressed air delivered at the point of end-use (kWh/m3) at a stated pressure level - Share of the machines with automatic closing of the compressed air delivery pipe when the machine is not in use (%) - Air leakage index which is calculated when all air consumers are switched off as the sum for each of the compressors of the time it runs multiplied by the capacity of that compressor, divided by the total standby time and the total rated capacity of the compressors in the system: $Air\ Leakage\ Index = \frac{\sum_i t_{i(cr)} * C_{i(cr)}}{t_{(sb)} * C_{(tot)}}$	- The electricity use of the compressed air system is lower than 0.11 kWh/m³ of delivered compressed air, for large installations working at 6.5 bars effective, with volume flow normalized on 1013 mbar and 20°C, and pressure deviations not exceeding 0.2 bars effective.
3.5 Use of renewable energy	- Share of electricity from renewable sources (self-generated or purchased) out of the total energy use (%) - Share of heat from renewable sources out of the total heat use (%)	- All electricity use is met by self-generated or purchased verified renewable electricity. - The use of renewable heat generated on-site is integrated in suitable manufacturing processes
3.6 Rainwater collection	- Share of rainwater use on total water use (%)	- Rainwater is collected and used as process water in manufacturing and ancillary processes.
Manufacturing processes		
4.1 Selection of resource-efficient Metal Working Fluids	- Total amount of metal working fluids purchased per year (kg (or l)/year) - Total amount of recovered metal working fluids per year (kg (or l)/year) - Number of different metal working fluids used in the company (total number of metal working fluids) - Consumption of MWFs per manufactured product (kg (or l)/ kg finished product or manufactured part)	The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement in, at least, the following indicators: • energy use per manufactured product • resources efficiency • consumption of metal working fluids per manufactured product

BEMPs	Key environmental performance indicators	Benchmarks of excellence
4.2 Minimisation of lubricoolant use in metal processing	- Consumption of lubricoolants per processed part (l/part)	The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement in, at least, the following indicators: • energy use per manufactured product • resources efficiency • consumption of metal working fluids per manufactured product
4.3 Incremental sheet metal forming as alternative for mould making	- Energy use per manufactured product (kWh / kg finished product or manufactured part) - Resource efficiency (kg finished product / kg of material input) - Environmental benefits of switching to ISF are proven by a full LCA or a simplified LCA based on quantitative analysis (Y/N)	The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement in, at least, the following indicators: • energy use per manufactured product • resources efficiency • consumption of metal working fluids per manufactured product
4.4 Reduction of standby energy use of metal working machines	- Energy use per manufactured product (kWh / kg of finished product or manufactured part) - For individual relevant machines: Total energy use per and year (kWh / year) - For individual relevant machines: energy use during downtime (kWh / hour) (kWh/hour) - Percentage of machines having a switch-off/do-not-switch label (%)	All metal working machines have either a green standby mode or a label indicating when they should be manually switched off.
4.5 Maintaining material value for metal residues	- Oil recovered (l oil / year) - Oil resource efficiency (% of oil in briquettes or separator output)	Turning chips and grinding swarf have oil/moisture content respectively lower than 2% and 8%
4.6 Multi-directional forging	- Percentage of generated flash per manufactured part (%) - Total energy required for the forging process (energy input for the	The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement

BEMPs	Key environmental performance indicators	Benchmarks of excellence
	forging process kWh / kg finished product or manufactured part) - Resource efficiency (kg finished product or manufactured part / kg of material input)	in, at least, the following indicators: • energy use per manufactured product • resources efficiency • consumption of metal working fluids per manufactured product
4.7 Hybrid machining as a method to reduce energy use	- Energy use (kWh / kg finished product or manufactured part) - Resource efficiency (kg finished product or manufactured part / kg of material input)	The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement in, at least, the following indicators: • energy use per manufactured product • resources efficiency • consumption of metal working fluids per manufactured product
4.8 Use of predictive control for paint booths HVAC management	- Energy use for painting (kWh/ m^2 of surface coated/painted)	The company achieves continuous (i.e. year-on-year) improvement in environmental performance as reflected by an improvement in, at least, the following indicators: • energy use per manufactured product • resources efficiency • consumption of metal working fluids per manufactured product

List of abbreviations and definitions

BAT	Best available technique
BEMP	Best environmental management practice
BRef	BAT Reference Document
ECDM	Environmentally Conscious Design and Manufacturing
EDM	Electrical Discharge Machining
FMP	Ferrous Metals Processing Industry
GHG	Greenhouse Gases
HVAC	Heating, Ventilating, and Air Conditioning
LCA	Life Cycle Analysis
NMVOS	Non-Methane Volatile Organic Compounds
WEEE	Waste Electrical and Electronic Equipment

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