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Background report on best environmental management practice in the fabricated metal product manufacturing sector

Study by VITO in collaboration with Sirris and Agoria for the European Commission's Joint Research Centre

December 2015

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Abstract

This document is a background report supporting the elaboration of a sectoral reference document on best environmental management practice for the Manufacturing of Fabricated Metal Products. It provides guidance on techniques, measures and actions which allow organisations in the Fabricated Metal Products sector to minimize their impact on the environment in all the aspects under their direct control (direct environmental aspects) or on which they have a considerable influence (indirect environmental aspects).

This activity is part of the European Commission's Joint Research Centre (JRC) work on the identification of best environmental management practices (BEMPs) and the development of Sectoral Reference Documents under the EU Eco-Management and Audit Scheme (EMAS).

The document first describes proposed BEMPs for supporting processes, divided into BEMPs for management, procurement and supply chain management (3) and for the optimization of utilities (7). BEMPs on manufacturing processes are then described, divided into four process groups: BEMPs for all manufacturing processes (4), for forming processes (3), for removing processes (2), for finishing processes (2). Finally two BEMPs on concurrent engineering and product design define how the environmental impact within the value chain of companies manufacturing fabricated metal products can be minimized.

Résumé

Ce document est un rapport préliminaire servant de base à l'élaboration d'un document de référence sectoriel sur les meilleures pratiques de management environnemental dans le secteur de la fabrication de produits métalliques. Il fournit des conseils sur les techniques, les mesures et actions qui permettent aux entreprises du secteur de réduire leur impact sur l'environnement, pour tous les aspects qui se trouvent directement sous leur contrôle (aspects environnementaux directs) ou pour les aspects sur lesquels elles ont une influence importante (aspects environnementaux indirects).

Cette activité fait partie du travail du Centre Commun de Recherche de la Commission Européenne (JRC) sur l'identification des meilleures pratiques de management environnemental (MPME) et le développement des Documents de Référence Sectoriels dans le cadre du Système européen de management environnemental et d'audit (EMAS).

Ce document décrit tout d'abord les propositions de MPMEs relatives aux procédés de support, divisées en pratiques de gestion, d'approvisionnement et de gestion de la chaîne logistique (3) et en pratiques pour l'optimisation des fournitures de services (7). Par la suite sont décrites les MPMEs relatives aux procédés de fabrications, qui sont divisées en quatre groupes : les MPMEs applicables à tous les procédés de fabrication (4), les MPMEs relatives aux procédés de formage (3), les MPMEs relatives aux procédés de décapage (2) et les MPMEs relatives aux procédés de finition (2). Les deux dernières meilleures pratiques, relatives à l'ingénierie simultanée (concurrent engineering) et à la conception de produits définissent comment l'impact environnemental le long de la chaîne de valeur des fabricants de produits métalliques peut être minimisé.

Executive summary

The European Commission's Joint Research Centre (JRC) is developing a sectoral reference document on best environmental management practice for the Manufacture of Fabricated Metal Products[1]. This will be a guidance document on techniques, measures and actions, which allow organisations in the sector to minimise their impact on the environment in all the aspects under their direct control (direct environmental aspects) or on which they have a considerable influence (indirect environmental aspects). This activity is part of the JRC's work on the identification of best environmental management practices and the development of Sectoral Reference Documents under the EU Eco-Management and Audit Scheme (EMAS). This brief introduction outlines the proposed scope and priorities of the project and provides a provisional list of proposed Best Environmental Management practices (BEMPs) for the sector.

The work will cover the most relevant manufacturing and supporting activities and processes of the Fabricated Metal Products sector, such as forming processes, removing processes, additive and welding processes and finishing processes. The primary manufacturing of iron, steel and non-ferrous metals is not included in the scope of the document. For all activities and processes within the scope, BEMPs will be identified both of a technical and/or technological nature, such as improving the energy efficiency of a certain process, and of a more organisational or management type, such as chemical leasing or engaging in environmental improvement with suppliers. BEMPs will be identified not only within the physical site boundaries of organisations belonging to the sector, but also looking at minimising environmental impacts across the entire value chain. Besides BEMPs that improve the environmental performance of the Fabricated Metal Products sector, BEMPs contributing to an improvement of the environmental performance of other related sectors are also considered (Figure 1). In particular, BEMPs on concurrent engineering and product design define precisely how the environmental impacts within the value chain of Fabricated Metal Product manufacturing companies can be minimised.

[1] For more information, see http://susproc.jrc.ec.europa.eu/activities/emas/fab_metal_prod.html

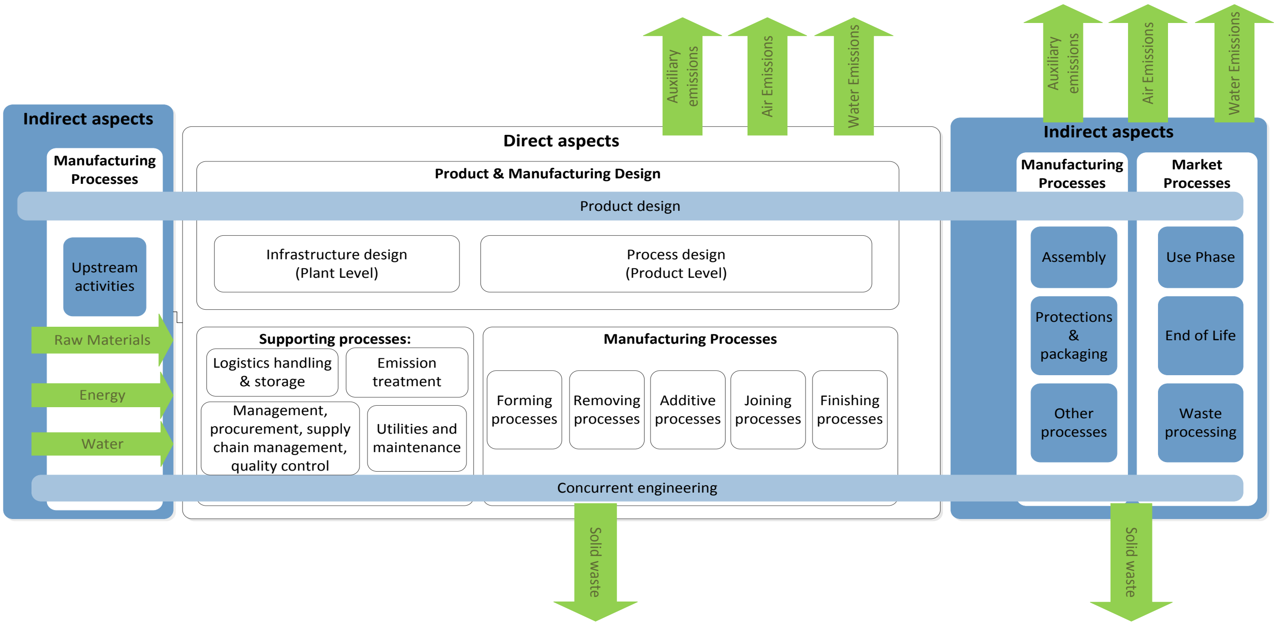


Figure 1. Schematic overview of the direct and indirect aspects and environmental pressures of the Fabricated Metal Products sector

JRC contracted VITO, Sirris and Agoria to support the identification of the main environmental issues for the sector, and put forward proposals of BEMPs and environmental performance indicators. These proposals are summarised below and will be the basis for discussion with stakeholders via the forum of a European Technical Working Group (TWG) of sectoral experts to be established in Summer-Autumn 2016.

Expressions of interest to join the TWG can be sent to JRC-IPTS-EMAS@ec.europa.eu.

Structure of the work and proposed BEMPs

The proposed BEMPs for supporting processes are divided into *management, procurement* and *supply chain management:*

- **Extend the lean principles with measures for energy and material consumption** describes an overall approach for reducing the amount of energy and material used in Fabricated Metal Product manufacturing companies;

- By taking effective **Measures for stock reduction – while keeping customer demand flexibility**, the lead time will be lower. This results not only in smaller stock and less work in progress but also in less non-conforming products and a lower environmental impact.

- **Cross-sectoral and value chain collaboration (by communication and integration)** lead to a reduction of the environmental impact over the value chain;

- By means of **Chemical leasing & Chemical management services,** Fabricated Metal Products manufacturers can reduce the amount of waste generated, and emission of chemicals used in the various manufacturing processes;

and *BEMPs for optimisation of utilities within the Fabricated Metal Products organisations*:

- The BEMP on **Energy management** describes an overall approach for reducing and optimising the energy use within the organisations of the sector. The five following BEMPs specify how this can be achieved for the different utilities and process lines;

- **Efficient ventilation** deals with the minimisation of the ventilation needs, as well as with the optimisation of the ventilation system design and use;

- **Optimal lighting** adapted to the specific needs of the production line, storage rooms, utility rooms, offices etc. results in better light quality, better working conditions and a lower electricity consumption;

- **Energy and water savings of cooling circuits** deals with the systematic approach of reducing the cooling needs, using and optimising the cooling design;

- **Efficient use of compressed air systems** by minimising pressurised air needs and optimising the system's design and use, results in a lower overall energy use;

- The implementation of smart tools (switches, software, PLC steering, etc.) on machines results in a **Reduction of standby energy of metal working machines.**

BEMPs on manufacturing processes are divided into four process groups. The following *BEMPs are applicable for all manufacturing processes*:

- **Application of solid low-friction coatings on tools and components** and **Application of wear and corrosion-resistant coatings of tools and equipment** are two BEMPs where the surface of tools and equipment is changed. The first BEMP results in a longer lifetime of the tools and a reduction of lubricoolant use in the production process. The second one focuses on the protection of the underlying materials from corrosive elements, resulting in longer lifetime of tools and produced goods;

- There are two main trends in eco-efficient cooling for machining operations: cryogenic cooling and Minimum Quantity Lubrication (MQL). The BEMP **Selection of coolant as environmental and performance criterion** results in a significant reduction of lubricant use.

BEMPs for forming processes:

- **Incremental Sheet metal Forming (ISF) as alternative for mould making** leads to lower material use. The technique starts from metal sheets, which are formed by punching;

- **Additive manufacturing of complex equipment - flow optimization for optimal heat transfer and temperature control** gives a solution for shaping complex metal pieces by using a limited amount of raw materials;

- **Multi-directional forging: a resource efficient metal forming alternative** for complex geometric pieces in large series leads to lower material and energy use.

BEMPs for removing processes:

- Manufacturing processes that combine two or more established processes are described in **Hybrid machining as a method to reduce energy consumption**;

- **Machining of near-net-shape feedstock** uses products which initial form is very close to the final product's geometry. This results in a reduction of the number of finishing operations.

BEMPs for finishing processes:

- **Reduce the energy for paint booth HVAC with predictive control** is done 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 by the HVAC unit;

- **Selection and optimization of thermal processes for curing wet-chemical coatings on metal products** leads to lower energy use for curing. It comprises a combination of choosing the optimal paintings and coatings and the optimal drying technique (room curing, high temperature curing, IR or UV curing).

The two proposed BEMPs on concurrent engineering and product design provide guidance on how the environmental impacts within the value chain of companies, which belong to the manufacture of fabricated metal products, can be minimised:

- By dismantling products, which contain high value materials and pieces, the latter can be reassembled into new products. The **Remanufacturing of high value components** does not only have a positive impact in the Fabricated Metal Products company itself, but also up- and downstream in the value chain;

- **Co-design and open innovation with downstream partners to reduce environmental impact during product life cycle** leads to new products and product designs. During the design phase, all aspects of the production, use and reuse are taken into account.

Companies from the fabricated metal products sector interested in implementing best practice in the improvement of environmental performance are recommended to refer instead to the final Best Practice Report that will be available on-line[2] as soon as it is finalised and published.

[2] The Best Practice Report will be available online at http://susproc.jrc.ec.europa.eu/activities/emas/fab_metal_prod.html

Synthèse

Le Centre Commun de Recherche (JRC) de la Commission européenne établit un document de référence sectoriel sur les meilleures pratiques de management environnemental dans le secteur de la fabrication de produits métalliques. Ce document fournira des conseils sur les techniques, les mesures et actions qui permettent aux entreprises du secteur de réduire leur impact sur l'environnement, pour tous les aspects qui se trouvent directement sous leur contrôle (aspects environnementaux directs) ou pour les aspects sur lesquels elles ont une influence importante (aspects environnementaux indirects). Cette activité fait partie du travail du JRC sur l'identification des meilleures techniques de gestion de l'environnement et le développement des Documents de Référence Sectoriels dans le cadre du Système européen de management environnemental et d'audit (EMAS). Cette introduction explique le cadre proposé et les priorités du projet. En outre, une liste des meilleurs pratiques de gestion environnementale est présentée.

Le projet couvrira les principaux procédés de fabrication et de support du secteur FPM tels que les procédés de formage, les procédés d'usinage, les procédés additifs et de soudage, et les procédés de finition. Le document ne couvrira pas la fabrication de base du fer, de l'acier et des métaux non ferreux.

Pour chaque activité et procédé relevant du champ d'application, les meilleurs pratiques de management environnemental (MPMEs) seront identifiées, sur le plan technique ou technologique, comme l'amélioration de l'efficience énergétique de certains procédés, ou un mode amélioré de gestion ou d'organisation, tels que le leasing de produits chimiques, ou les démarches d'amélioration auprès des fournisseurs.

Les MPMEs seront identifiées non seulement à l'intérieur des limites physiques du site des entreprises du secteur FPM, mais aussi en cherchant à réduire les impacts environnementaux à travers l'intégralité de la chaine de valeur.

En plus des MPMEs qui améliorent les performances environnementales du secteur FPM, les pratiques qui contribuent à améliorer les performances environnementales d'autres secteurs seront aussi considérées (**Error! Reference source not found.Error! Reference source not found.**).Plus spécifiquement les MPMEs relatives à l'ingénierie simultanée et à la conception de produits définissent plus précisément comment l'impact environnemental le long de la chaine de valeur peut être réduit.

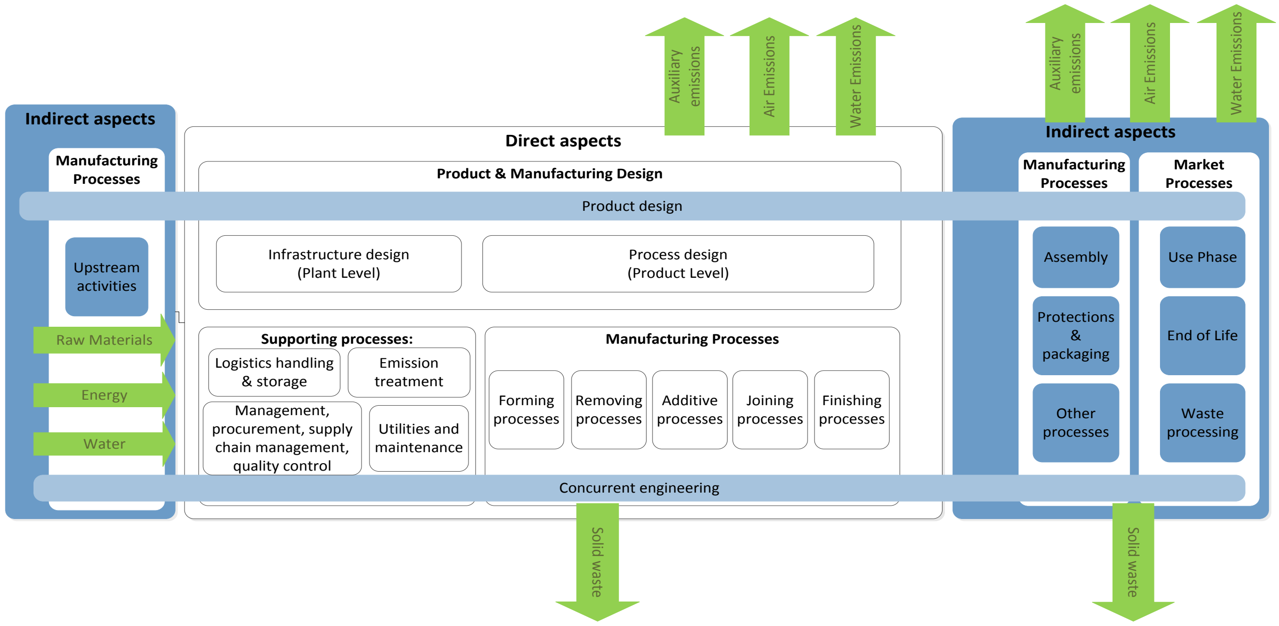


Figure 2. Aperçu schématique des aspects directs et indirects et des pressions environnementales du secteur FPM

Le JRC a sous-traité à VITO, Sirris et Agoria la mission d'étayer l'identification des aspects environnementaux du secteur et de proposer des MPMEs et des indicateurs de performance. Ci-dessous, la liste proposée des MPMEs est présentée, qui formera la base de la discussion avec les parties prenantes via le forum d'un groupe de travail technique européen (GTT) des experts sectoriels, à établir entre l'été et l'automne 2016.

Les manifestations d'intérêt pour rejoindre le GTT peuvent être envoyées à JRC-IPTS-EMAS@ec.europa.eu[3]

Les propositions de MPMEs relatives aux procédés de support sont divisées en pratiques de *gestion,* d'*approvisionnement* et de *gestion de la chaîne des fournisseurs:*

- **Etendre les principes de "flux tendu" aux mesures pour la consommation d'énergie de matériaux** décrit une approche globale pour réduire la quantité d'énergie et de matériaux utilisés dans les entreprises FPM;
- En mettant en place des **mesures pour la réduction des stocks – tout en conservant la flexibilité face à la demande des clients**, le délai de livraison se réduira. Par conséquent, le stock sera plus faible et engendrera moins de travail, mais aussi moins de produits non conformes et un impact environnemental plus faible;
- **La collaboration entre secteurs et à travers la chaîne de valeur (communication et intégration)** mène à une réduction de l'impact environnemental le long de la chaîne de valeur;
- Au moyen de **leasing de produits chimiques & de services de gestion chimique,** les entreprises FPM peuvent réduire les quantités de déchets générés, et l'émission de produits chimiques utilisé dans leurs process.

Et les *MPMEs pour l'optimisation des services utilitaires*:

[3] N.B. les discussions du GTT se font par défaut en anglais.

- La MPME sur **la gestion de l'énergie** décrit une approche globale pour réduire la consommation et l'utilisation d'énergie. Les six MPMEs suivantes spécifient comment le mettre en œuvre pour différents services et lignes de transformation;
- **La ventilation efficace,** en minimisant les besoins de ventilation et en optimisant sa conception et son utilisation, a pour résultat de diminuer la consommation énergétique globale;
- **L'éclairage optimal,** adapté aux besoins spécifiques des lignes de production, des espaces de stockage, des zones utilitaires, des bureaux, etc. a pour résultat une meilleure qualité de lumière, de meilleures conditions de travail et une moindre utilisation de l'électricité;
- Une approche systématique pour réduire les besoins de refroidissement, optimiser la conception des installations et leur utilisation mène à des **économies d'énergie et d'eau dans les circuits de refroidissement**;
- **L'utilisation efficace des systèmes d'air comprimé,** en minimisant les besoins d'air comprimé et en optimisant la conception et l'utilisation de l'installation, a pour résultat de diminuer la consommation énergétique globale;
- La mise en place d'outils intelligents (commutateurs, logiciel, API, etc.) sur les machines a pour résultat une **réduction de l'énergie utilisée en mode veille des machines de travail du métal.**

Les MPMEs relatives aux <u>procédés de fabrications</u> sont divisées en quatre groupes. Les *MPMEs applicables à tous les procédés de fabrication*:

- **Revêtements solides à faible coefficient de friction** et **application de revêtements résistants à l'usure et à la corrosion sur des outils et des équipements** sont deux MPMEs se rapportant à des procédés où la surface des outils et des équipements est modifiée. La première MPME a comme résultat d'augmenter la durée de vie des outils et de réduire l'utilisation d'agents lubrifiants dans le procédé de production. La seconde augmente la durée de vie des outils et des produits;
- Il existe deux tendances majeures pour le refroidissement éco-efficace des opérations d'usinage : le refroidissement cryogénique et l'utilisation minimale de la lubrification (Minimum Quantity Lubrication - MQL). La MPME sur la **sélection de fluides de refroidissement sur base de critères environnementaux et de performance** a pour résultat de réduire totalement ou partiellement l'utilisation d'agents lubrifiants

Les MPMEs relatives aux procédés de formage:

- **L'utilisation du formage incrémental (Incremental Sheet metal Forming (ISF) comme alternative à la fabrication de moules** mène à une diminution de l'utilisation des matériaux. La technique utilise des feuilles de métal qui sont formées par poinçonnage;
- **La fabrication additive d'équipements complexes – optimisation des flux pour un transfert de chaleur et un contrôle de température optimal** donne une solution de mise en forme des pièces métalliques complexes en utilisant une quantité limitée de matières premières;

- **Le forgeage multi-directionnel comme alternative efficace en ressource au formage** pour des pièces à la géométrie complexe en grandes séries mène à réduire l'utilisation de matériaux et d'énergie.

Les MPMEs relatives aux procédés d'usinage:

- Les procédés de fabrication qui combinent deux procédés bien établis ou plus sont décrits dans **l'usinage hybride comme méthode pour réduire la consommation d'énergie**;
- **L'usinage de pièces à forme quasi-définitive** utilise des pièces brutes dont la forme initiale est très proche de la géométrie du produit final. Il en résulte une réduction du nombre des opérations de finition.

Et les MPMEs relatives aux procédés de finition:

- **La réduction de l'utilisation d' énergie dans les cabines de peinture avec contrôle CVC prédictif** est réalisée d'une part, en enregistrant la température réelle et l'humidité de l'air entrant dans la cabine de peinture, et d'autre part, en conditionnant cet air de façon optimale pour la polymérisation, ce qui résulte en une consommation moindre des installations de CVC.
- **La sélection et l'optimisation des procédés thermiques pour le durcissement des revêtements chimiques humides sur les produits métalliques** mène à une diminution de l'utilisation d'énergie. Cela comprend à la fois la sélection optimale des peintures et revêtements et la sélection de la technique optimale de séchage (température ambiante, haute température, IR ou UV).

Deux MPMEs relatives à l'ingénierie simultanée (concurrent engineering) et à la conception de produits définissent comment l'impact environnemental le long de la chaîne de valeur des fabricants de produits métalliques peut être minimisé.

- En démontant les produits qui contiennent des matériaux et des pièces à haute valeur ajoutée, ces derniers peuvent être réassemblés dans de nouveaux produits. La **remise à neuf des composés de grande valeur** a un impact positif non seulement sur les entreprises FPM mais aussi en aval de la chaîne de valeur;
- **Le co-design et l'innovation ouverte avec des partenaires en aval pour réduire l'impact environnemental durant le cycle de vie du produit** mène à la conception de nouveaux produits. Durant la phase de conception, tous les aspects de la production, de l'utilisation et de la réutilisation du produit sont pris en compte.

Les entreprises du secteur intéressées par la mise en place de meilleures pratiques pour améliorer leur performance environnementale devraient se référer au Rapport final sur les Meilleures Pratiques qui sera disponible en ligne[4] dès sa finalisation.

[4] Le Rapport sur les Meilleures Pratiques sera disponible en ligne (en anglais) sur http://susproc.jrc.ec.europa.eu/activities/emas/fab_metal_prod.html

Table of contents

Abstract 4
Résumé 4
Executive summary 5
Synthèse 9
Table of contents 13
List of figures 15
List of tables 18
List of acronyms 20
Preface 21
CHAPTER 1. General information on the Fabricated Metal Products sector and definition of the scope 24
1.1. Composition of the Fabricated Metal Products sector 24
1.2. Economic relevance of the Fabricated Metal Product manufacturing sector 28
1.3. Main environmental aspects and pressures of the Fabricated Metal Product manufacturing sector 29
1.3.1. Environmental aspects 29
1.3.2. Environmental pressures and impacts 34
1.4. EMAS and the Fabricated Metal Product manufacturing sector 45
1.5. EU legislation, policy instruments and best practice guidance 46
1.6. Conclusions and Scope Best environmental management practice in the Fabricated Metal Product manufacturing sector 84
CHAPTER 2. Best environmental management practice 91
2.1. Technique portfolio 91
2.2. Best environmental management practices for the supporting processes 97
2.2.1. Extend the lean principles with measures for energy and material consumption 98
2.2.2. Measures for stock reduction - while keeping customer demand flexibility 107
2.2.3. Cross-sectoral and value chain collaboration (by communication and integration) 114
2.2.4. Chemical leasing & Chemical management services 125
2.2.5. Energy management 132
2.2.6. Efficient ventilation 136
2.2.7. Optimal lighting 145
2.2.8. Energy and water savings of cooling circuits 154
2.2.9. Efficient use of compressed air systems 162
2.2.10. Reduction of standby energy of metal working machines 175
2.3. Best environmental management practices for the manufacturing processes 181
2.3.1. Application of solid low-friction coatings on tools and components 182
2.3.2. Application of wear- and corrosion-resistant coatings of tools and equipment 188
2.3.3. Selection of coolant as environmental and performance criterion 194
2.3.4. Incremental Sheet metal Forming (ISF) as alternative for mold making 206
2.3.5. Additive manufacturing of complex equipment - flow optimization for optimal heat transfer and temperature control 215
2.3.6. Multi-directional forging: a resource efficient metal forming alternative 222
2.3.7. Hybrid machining as a method to reduce energy consumption 229
2.3.8. Machining of near-net-shape feedstock 235

2.3.9. Reduce the energy for paint booth HVAC with predictive control 239
2.3.10. Selection and optimization of thermal processes for curing wet-chemical coatings on metal products 245
2.4. Concurrent engineering and product design as Best environmental management practice 252
2.4.1. Remanufacturing of high value components 252
2.4.2. Co-design and open innovation with downstream partners to reduce environmental impact during product life cycle 262
References **Error! Bookmark not defined.**

List of figures

Figure 1. Schematic overview of the direct and indirect aspects and environmental pressures of the Fabricated Metal Products sector ... 6
Figure 2. Aperçu schématique des aspects directs et indirects et des pressions environnementales du secteur FPM ... 10
Figure 3. Share of enterprise size classes (by number of persons employed) of total manufacturing (Division C 10-33) and Fabricated Metal Product manufacturing (Division 25 and groups) (Eurostat, 2011) ... 27
Figure 4. The 10 countries with the highest number of Fabricated Metal Products enterprises (NACE 25) within the EU-28 (Eurostat, 2011) ... 28
Figure 5. Relative share of turnover for the NACE division 25 groups; total turnover equalled 472,000 million euros (Eurostat, 2011) ... 28
Figure 6. Organizational and temporal scale of environmental impact reduction approaches. Based on Coulter et al. (1995) and Bras (1997). Red line: scope of this study ... 31
Figure 7. Schematic overview of the direct and indirect aspects and environmental pressures of the Fabricated Metal Products sector ... 33
Figure 8. Relative share of direct and indirect emissions of the Fabricated Metal Products sector (EORA, 2011) ... 42
Figure 9. Basis: Shankey diagram of steel flow – the activities of the Fabricated Metal Product manufacturing sector are situated in the green area (Rolling and forming process) (Allwood, 2011); black line: NACE 25; double red line: scope of this study ... 43
Figure 10. Basis: Shankey diagram of aluminium flow – the activities of the Fabricated Metal Product manufacturing sector are situated in the green area (Rolling and forming process). (Allwood, 2011) black line: NACE 25; double red line: scope of this study ... 44
Figure 11. Lean waste concept can be translated into energy terms and is strengthened by two additional levers (http://www.mckinsey.com) ... 99
Figure 12. Five-step process for implementing lean principles in a company (Lean Enterprise Institute, 2015) ... 100
Figure 13. Principles of the Value Stream Method (Franhofer, 2011) ... 102
Figure 14: Energy Value Stream Analysis is similar representation as classic VSM visualisation (Fraunhofer, 2011) ... 103
Figure 15. Production of a front bumper made of 5 parts in 4 production steps – calculation of energy intensity demonstrates effect of product related approach (Fraunhofer, 2011) ... 103
Figure 16. Example Value Stream Map shows a value stream map from a value and energy stream (EPA, 2011) ... 104
Figure 17. Scheme of a traditional organization of the shop floor (Teim, 2010) ... 108
Figure 18. Organization of the shop floor: before: traditional functional layout; after: cellular layout (Teim, 2010) ... 108
Figure 19. Evolution of the energy use (kWh) per added value after implementing a QRM at Provan (Sirris, Provan, 2015) ... 111
Figure 20. Representation of Industrial Ecology processes (GPEM, 2015) ... 115
Figure 21. The Brainform re-use program (Brainform, 2015) ... 117
Figure 22: DENSO filtercake (NISP, 2012) ... 119
Figure 23: Oily grinding cake (NISP, 2009) ... 119
Figure 24: Agfa's old scrap flow (Pellegroms, 2015) ... 120
Figure 25: Agfa's new scrap flow (Pellegroms, 2015) ... 120
Figure 26: Carbon footprint Agfa (Verschave, 2012) ... 121
Figure 27. ChL business model compared to the conventional business model (Dow Safechem 2015) ... 126
Figure 28. Case study illustrating the potential of ChL (The Guardian, 2014, based on data from Ecolab, Stockmeier, Johnson). ... 128

Figure 29. 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) 139
Figure 30: 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) 140
Figure 31. Savings by on-demand ventilations (Litomisky, 2006) 142
Figure 32. Plant and heat pump load (Heemer et al, 2011) 155
Figure 33. Hybrid systems offers different operation mode: for dry, adiabatic and wet-dry cooling (Baltimore Aircoil, 2015) 158
Figure 34. Cost comparison between hybrid cooling towers and conventional wet cooling systems. 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 (Seneviratne M., 2007 ; based on data of Balimore Aircoil) 159
Figure 35: Potential saving related to compressed air (Ceati, 2007) 170
Figure 36: Energy management in a CNC controller (Heidenhain, 2010) 176
Figure 37: Power requirement for roughing (top) and finishing (bottom) milling of the housing (Heidenhain, 2010) 177
Figure 38: Machine power requirement 178
Figure 39: Energy profile for a CO_2 laser (Kellens et al. 2013) 178
Figure 40. Comparison of frictional performance; BALINIT is a solid low-friction coating (Oerlikon Balzers, 2010) 183
Figure 41. Solid low-friction coating (BALINIT C) in dry running and starved lubrication (gear test) (Oerlikon Balzers, 2010) 184
Figure 42. Machining cost and impact of a 20% increased cutting speed with high quality tools (Sandvik, 2008) 190
Figure 43. Metal working fluid (MWF) costs in metal machining (DGUV, 2010) 194
Figure 44. Cryogenic cooling solution on milling tool (Composite machining, 2014) 195
Figure 45. Tool lifetime in turning with Liquid Nitrogen Coolant (LIN) compared to Dry and Regular Cooling (AMT, 2015) 195
Figure 46. Wet and MQL cooling (Guhring, 2013) 196
Figure 47. Comparison of flows in conventional and cryogenic machining (Pušavec and Kopač, 2011) 197
Figure 48. Comparison of cost per part (Pušavec and Kopač, 2011) 199
Figure 49. External and internal lubrication feed (DGUV, 2010) 200
Figure 50. Saving potential for MQL (Guhring, 2013) 203
Figure 51. Process principle of incremental sheet forming, ISF (ISF-Light, 2012) 207
Figure 52. Incremental sheet metal forming installation (INMA, 2014) 207
Figure 53. Platforms used for ISF, from left to right: CNC milling machine, industrial robot, dedicated machine (Aminio, 2015) 208
Figure 54. Current and potential fields of application of incremental sheet forming (Ames, 2008) 210
Figure 55. Supporting tool in the background of the mold for a bothtub (Nordic Industrial Fund, 2003) 210
Figure 56. Dimensions of the piece used in this economical calculation (Lamminen et al, 2003) 211
Figure 57. Cost comparison diagram for incremental forming and deep drawing 212
Figure 58: Schematic view of layer by layer build up in additive manufacturing process 215
Figure 59. Hydrauvision heat exchanger 'Impossible-crossing' (Compolight, 2015) 216
Figure 60. Component that connects cooling circuits 218
Figure 61. Burner component from for Diametal 218
Figure 62. Injection mold insert with optimal cooling channels 218

Figure 63. Left: conventional burner consisting of over 20 parts, right: new AM burner made by AM out of one single piece 219
Figure 64. Significantly lower burr percentage: The multi-directionally forged crankshaft (right) compared with a conventionally forged one (IPH-Hannover, 2014) 222
Figure 65. Examples of components that can benefit from burr free and multidirectional forging (Hatebur, 2015) 223
Figure 66. Example of a burr free multi-directional forging sequence of a complex steel part (eg. crankshaft) (IPH-Hannover, 2015) 224
Figure 67. 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) 225
Figure 68. The adapted forging tools and the associated material flow in the burr free forging concept (b) leads to significant reduction or elimination of burr formation in comparison with the traditional set-up (a) (c) (IPH-Hannover, 2015) 225
Figure 69. CAD model of a multi-directional forging tool for the forging of a crankshaft. The arrows indicate the multiple directions of moving tool parts (IPH-Hannover, 2015)........ 226
Figure 70. Example of a multi-directional forging tool. It not only presses metal into the form from above but also at the same time from the sides. (IPH-Hannover, 2014). 226
Figure 71: Electrical Energy Requirement for different processes (Gutowski et al., 2006) 229
Figure 72: Hybrid process classification (Zhu et Al. 2013) 230
Figure 73: Hybrid micro Milling/EDM machine (WZL, RWTH Aachen)........ 232
Figure 74: Conventional Machining vs Laser Assisted Machining (LAM) (Anderson et Al. 2006)........ 233
Figure 75: Near net shape machining (Whitesell group, 2015) 235
Figure 76: Flowchart of MIM (Afraz, 2012)........ 236
Figure 77: Cold forming as a near net shape technology to allow less material waste, lower cost and lower lead times (Whitesell group, 2015) 237
Figure 78. Control window versus control point (Taikisha-group, 2015) 239
Figure 79. 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) 240
Figure 80. 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) 242
Figure 81. Differences between a conventional UV lamp and a UV led for curing (UV process, 2015)........ 247
Figure 82. Ecological fingerprint of six refinish primers (Wall et al., 2004)........ 247
Figure 83. Remanufacturing, restoring used products to useful life (CRR, 2013) 252
Figure 84. The RemPro-matrix showing the relationship between the preferable product properties and the generic remanufacturing process steps (Sundin, 2004) 253
Figure 85. BMA assembly – disassembly line (BMA-ergonomics, 2015) 254
Figure 86. Steel waiting for a buyer at the Portal Power plant (Allwood, J.M. et al, 2012 and Portal Power, 2015) 256
Figure 87. Rype Office offering (Rype Office, 2015) 257
Figure 88: Remanufacturing requires different aspects in the “three basic components of industry” to be balanced (Sirris/Agoria, 2015) 259
Figure 89. Impact of full remanufacturing on EBITDA and jobs in four sectors in the UK (Lavery et al, 2013) 259
Figure 90. Closed vs. open innovation (Chesbrough, 2003)........ 262
Figure 91. The ConX® System (Cradle to Cradle Certified Products Registry, 2014)........ 265
Figure 92: Curana’s turnover and profit in relation to the bicycle production (Bosch, 2010)........ 267

List of tables

Table 1. Overview of the NACE division 25 (Rev.2) groups and classes 24
Table 2. Number of enterprises in the Fabricated Metal Product manufacturing sector (NACE Rev.2 division 25 and groups) (Eurostat, 2011) 26
Table 3. Economic indicators of the EU-28 Fabricated Metal Product manufacturing sector (Eurostat, 2011)29
Table 4. Influence on indirect environmental pressures by companies in the Fabricated Metal Products sector (NACE 25) 35
Table 5. Assessment of the environmental pressures of the direct aspects (NACE 25) and interface processes of the indirect aspects 36
Table 6. Comparison of sector classification systems of EORA (UK) and NACE Rev.2 39
Table 7. Direct and total emissions and resource use of the Fabricated Metal Products (sub) sectors (Eurostat and EORA, 2011) 41
Table 8. Overview of EMAS registrations (registration numbers and organisations) in EU-28 in the Fabricated Metal Products sector (http://ec.europa.eu/environment/emas/register/)..... **Error! Bookmark not defined.**
Table 9. Global overview of processes/activities/techniques within the scope of BREFs (directly or indirectly) linked to the manufacture of Fabricated Metal Products 48
Table 10. Examples of direct environmental parameters covered in the BREFs (directly or indirectly) linked to the manufacture of Fabricated Metal Products 58
Table 11. Overview of the EU legislation, policy instruments and best practice guidance relevant for products and processes of the NACE 25 (sub)sectors 59
Table 12. Overview of the policy instruments relevant for products and processes of the NACE 25 (sub)sectors 71
Table 13. Overview of the best practice guidance relevant for products and processes of the NACE 25 (sub)sectors 74
Table 14. Most relevant direct environmental aspects for the Fabricated Metal Products companies how these are addressed 92
Table 15. Most relevant indirect environmental aspects for the Fabricated Metal Products companies how these are addressed 95
Table 16. Panimpex results of QRM implementation (Sirris, 2014) 111
Table 17. Energy management matrix 133
Table 18. Different type of cooling towers and their advantages and disadvantages, (based on Baltimore Aircoil, 2015; Seattle Public Utilities, 2015; US Department of Energy, 2011) 155
Table 19. Overview of the most common types of inappropriate use of compressed air in the Fabricated Metal Products Sector 163
Table 20. Overview of the main measures related to compressed air system configuration 165
Table 21. Sequence of steps that can be used to optimize the settings of compressed air systems 166
Table 22. Considerations for optimal maintenance of compressed air systems 167
Table 23. Examples of achievable energy saving through compressed air measures in an industrial context (Carbon Trust, 2012) 169
Table 24. Overview of auxiliary processes during standby mode (Duflou et al., 2011) 175
Table 25. Energy savings for several machines, comparison standby and shut down (Kellens et al., 2013)179
Table 26. Advantages and disadvantages of applying solid low-friction coatings 182
Table 27. Application of surface treatment processes (Oerlikon Blazers, 2010) 189
Table 28. Machining cost and impact of a 20% increased cutting speed with high quality tools (Sandvik, 2008) 191
Table 29. Examples of longer mold lifetime by using wear resistance coatings for the production of synthetic materials (FME CWM, 2005) 191
Table 30. Comparison of the LCA of emulsion and cryogenic cooling (Pušavec and Kopač, 2011) 198

Table 31. Advantages and disafvantages of external and internal feed of MQL (DGUV, 2010) 200
Table 32. Areas of application for minimum quantity lubrication and dry processing (DGUV, 2010) 201
Table 33. Examples of areas of minimum quantity lubrication application with production processes and motivation (DGUV, 2010).. 202
Table 34. Comparison of deep drawing and incremental sheet forming parameters and unit costs (Lamminen et al, 2003)... 212
Table 35. Examples of hybrid machining processes (Fraunhofer, 2014).. 230
Table 36. A comparison of the toxicity & other properties of UV-curable ink components and some commonly used ink solvents (PNEAC) 248
Table 37. Total industrial installation and utility source emissions (metric tons/billion cans) (Golden, 2005) 249
Table 38. Total industrial installation and utility energy use (million BTU/billion cans) (Golden, 2005) 249

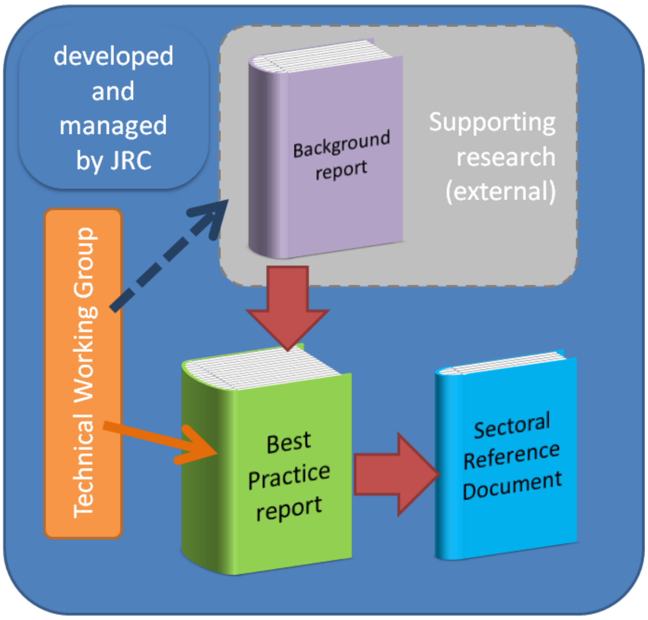
List of acronyms

BAT	Best available technique
B2B	Business to business
BEMP	Best environmental management practice
BREF	BAT Reference Document
BREF ENE	BAT Reference Document on Energy Efficiency
BREF FMP	BAT Reference Document on Ferrous Metals Processing Industry
BREF ICS	BAT Reference Document on Industrial Cooling Systems
BREF LCP	BAT Reference Document on Large Combustion Plants
BREF NFM	BAT Reference Document on Non Ferrous Metals Industries
BREF STM	BAT Reference Document on Surface Treatment of Metals and Plastics
BREF STS	BAT Reference Document on Surface Treatment using Organic Solvents
BREF WT	BAT Reference Document on Waste Treatment Industries
CE	Concurrent Engineering
ECDM	Environmentally Conscious Design and Manufacturing
EDM	Electrical Discharge Machining
EMAS	Eco-Management and Audit Scheme
GHG	greenhouse gases
HVAC	heating, ventilating, and air conditioning
LCA	Life Cycle Analysis
NMVOS	non-methane volatile organic compounds
VFD	Variable Frequency Drive
WEEE	Waste electrical and electronic equipment

Preface

This background report provides an overview of techniques that may be considered **Best Environmental Management Practices** (BEMPs) in the manufacture of fabricated metal products sector. The document was developed by VITO under a contract with the European Commission's Joint Research Centre (JRC) on the basis of desk research, interviews with experts and site visits. This background report is intended to provide a preliminary basis for further discussions between the JRC and technical experts via the forum of a Technical Working Group (TWG). **The contents of this report therefore represent early findings that will be further developed through discussions with the TWG**, according to a structured process 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[5].

The final findings will be presented in a best practice report produced by the JRC and used for the development of an EMAS Sectoral Reference Document (SRD), as illustrated below.



Source: JRC

Figure I: The present background report in the overall development of the Sectoral Reference Document (SRD)

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. 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 manufacture of fabricated metal products.

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

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

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

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

- (1) They have been implemented at full scale by several companies (or by at least one company if replicable/applicable by others);
- (2) 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 sector of fabricated metal products, 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 I.

Table I: 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.
Operational data	Operational data that can help understand the implementation of a BEMP, including any issues experienced. This includes actual and plant-specific performance data where possible.
Applicability	Indication of the type of plants or processes in which the technique may or may not be applied, as well as constraints to implementation in certain cases.
Economics	Information on costs (investment and operating) and any possible savings (e.g. reduced raw material or energy consumption, waste charges, etc.).
Driving force for implementation	Factors that have driven or stimulated the implementation of the technique to date.

Category	Type of information included
Reference organisations	Examples of organisations that have successfully implemented the BEMP.
Reference literature	Literature or other reference material cited in the information for each BEMP.

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

- Environmental Performance Indicators represent the metrics that are employed by organisations in the sector to monitor either the implementation of the BEMPs described or, when possible, directly their environmental performance.
- 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 are drawn by the TWG at the end of its interaction with the JRC. Therefore the proposals for indicators (and, eventually, for benchmarks) contained in this background report are to be considered no more than preliminary proposals from the authors of this background report.

Role and purpose of this document

The present background report provides a basis to be used by the JRC and Technical Working Group for the elaboration of the "JRC Scientific and Policy Report on Best Environmental Management for the fabricated metal products sector", or simply "Best Practice Report", containing the technical basis for the Sectoral Reference Document (SRD).

Companies from the fabricated metal products sector interested in implementing best practice in the improvement of environmental performance are recommended to refer instead to the final Best Practice Report that will be available on-line[6] as soon as it is finalised and published.

[6] The Best Practice Report will be available online at http://susproc.jrc.ec.europa.eu/activities/emas/fab_metal_prod.html

CHAPTER 1. General information on the Fabricated Metal Products sector and definition of the scope

1.1. Composition of the Fabricated Metal Products sector

→ **NACE Rev. 2 Division 25**

The industrial sector investigated in this study is the **Manufacture of Fabricated Metal Products**, except machinery and equipment in the EU-28. Throughout the document, the sector will be referred to under that name, "Fabricated metal product manufacturing", "Metal fabrication", "the Fabricated Metal Products sector" or simply (unless otherwise specified) "the sector".
This sector is 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 NACE division 25 is composed of eight groups and further subdivided in classes (Table 1).

Table 1. Overview of the NACE division 25 (Rev.2) groups and classes

NACE code	*Description*
C	MANUFACTURING
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 boiler*
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
25.61	*Treatment and coating of metals*
25.62	*Machining*
25.7	Manufacture of cutlery, tools and general hardware
25.71	*Manufacture of cutlery*

NACE code	Description
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.*

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

Structural metal products include, e.g., metal frameworks or parts for construction. Steam generators include, e.g., generators for nuclear reactors or for power boilers. The manufacture of weapons and ammunition includes the manufacture of heavy weapons, small arms, air or gas guns and pistols, war ammunition, hunting, sporting or protective firearms and ammunition, explosive devices such as bombs, mines and torpedoes. Forging, pressing, stamping and roll-forming of metal and powder metallurgy as well as the treatment and coating of metals and machining are typically carried out on a fee or contract basis. The treatment and coating of metals also includes plating, engraving, boring, turning, milling, sharpening, polishing and welding. The manufacture of other fabricated metal products includes the production of steel drums, containers, light metal packaging, nails, screws, bolts, nuts, springs, chains, as well as household and industrial fixtures.

Depending on the type of product and the business model of companies, they will produce end products for consumers or other companies (B2B); or they produce semi-finished products (B2B). Below we give some examples of possible value chains.

Fabricated Metal Product manufacturing sector as supplier of semi-finished products:
- Sector company A produces metal tanks and reservoirs (NACE 25.29), which will be used by a producer of small combustion plants, tank infrastructure;
- Sector company B produces metal structures (NACE 25.11), which will be used by building companies to produce (pre)fabricated concrete elements;
- Sector company C produces locks and hinges (NACE 25.72), which will be used by Sector company D for the manufacture of doors and windows (NACE 25.12).

Fabricated Metal Product manufacturing sector as supplier of end-products:
- Sector company E produces radiators (NACE 25.21) for consumers;
- Sector company F produces canes (NACE 25.92) for production of beverages (NACE 11).

In the economic analysis we focus on the division 25. Excluded from this division 25 are the manufacture of tanks and other fighting vehicles (included as part of the manufacture of other transport equipment, Division 30), the manufacture of metal

furniture (which is part of furniture manufacturing, Division 31), metal sports goods, games and toys (which are classified to other manufacturing, Division 32) and specialized repair, maintenance and installation activities, which form part of Division 33 (Eurostat, 2013).

→ **Number and size of Fabricated Metal Products enterprises**

The Fabricated Metal Product manufacturing sector within the EU-28 comprised 390 966 enterprises in 2011. This represents 19% of the total **number of enterprises** of the manufacturing (Section C) NACE divisions. The data of 2011 is 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.

Treatment and coating of metals; machining (Group 25.6) and Manufacture of structural metal products (Group 25.1) are the groups with the highest number of enterprises in the 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 2).

Table 2. Number of enterprises in the Fabricated Metal Product manufacturing sector (NACE Rev.2 division 25 and groups) (Eurostat, 2011)

NACE Rev.2	*Number of enterprises*	*Share of sector (division 25) (%)*
Manufacture of fabricated metal products, except machinery and equipment (Division 25)	*390 966*	*100*
Manufacture of structural metal products (Group 25.1)	122 050	31
Manufacture of tanks, reservoirs and containers of metal (Group 25.2)	5 507	1
Manufacture of steam generators (Group 25.3)	1 017	0
Manufacture of weapons and ammunition (Group 25.4)	1 277	0
Forging, pressing, stamping and roll-forming of metal and powder metallurgy (Group 25.5)	15 000	4
Treatment and coating of metals and machining (Group 25.6)	142 879	37
Manufacture of cutlery, tools and general hardware (Group 25.7)	52 300	13
Manufacture of other fabricated metal products (Group 25.9)	51 000	13

The sector is characterized 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.

According to this definition, only 0.3% of the Fabricated Metal Products enterprises in the EU-28 are categorized as large enterprises (2011). The largest share of enterprises (82%) has less than 10 persons employed. Apart from some small variations, the relative share of each size class is quite similar between the groups of NACE division 25 (Figure 3).

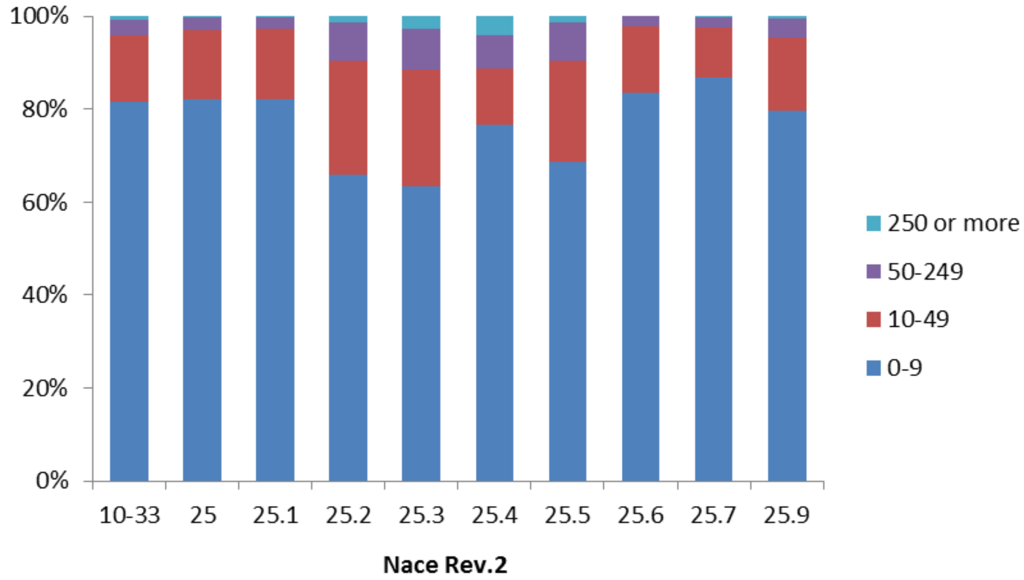


Figure 3. Share of enterprise size classes (by number of persons employed) of total manufacturing (Division C 10-33) and Fabricated Metal Product manufacturing (Division 25 and groups) (Eurostat, 2011)

→ **Geographical distribution**

In the EU-28, Italy has the highest number of Fabricated Metal Products enterprises (71 971; 18%), followed by Czech Republic (11%), Germany (11%), Spain (10%) and Poland (8%) (Eurostat, 2011) (Figure 4).

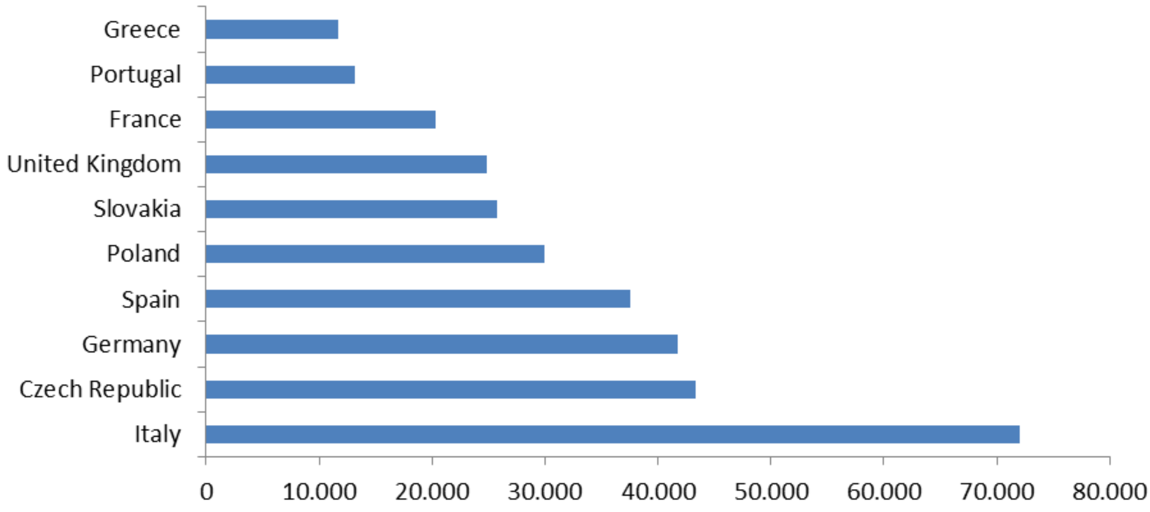


Figure 4. The 10 countries with the highest number of Fabricated Metal Products enterprises (NACE 25) within the EU-28 (Eurostat, 2011)

1.2. Economic relevance of the Fabricated Metal Product manufacturing sector

In 2011 the total turnover of the EU-28 Fabricated Metal Product manufacturing sector accounted for 472 000 million euros, representing 7% of the turnover of total manufacturing (division 10-33). The turnover significantly differs between the 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 5).

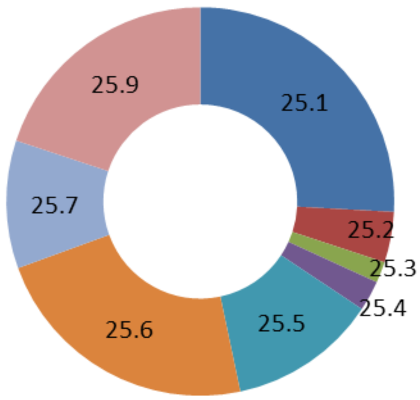


Figure 5. Relative share of turnover for the NACE division 25 groups; total turnover equalled 472,000 million euros (Eurostat, 2011)

Important economic indicators of the sector (turnover, added value at factor cost and the number of employees) and their distribution within the EU-28 are given in Table 3.

Table 3. Economic indicators of the EU-28 Fabricated Metal Product manufacturing sector (Eurostat, 2011)

region/country	*Turnover*		*Value added at factor cost*		*Number of employees*	
	Value (million €)	**Share (%)**	**Value (million €)**	**Share (%)**	**Value (million €)**	**Share (%)**
EU-28	472.000		159.000		3.340.000	
Belgium	13.077,3	*3*	3.846,8	*2*	56.113	*2*
Bulgaria	1.319,7	*0*	396,1	*0*	51.870	*2*
Czech Republic	12.067,4	*3*	3.434,2	*2*	135.735	*4*
Denmark	6.127,7	*1*	2.294,9	*1*	38.354	*1*
Germany	128.084,7	*27*	47.044,1	*30*	825.673	*25*
Estonia	1.091,1	*0*	252,2	*0*	11.539	*0*
Ireland	1.300,2	*0*	523,6	*0*	9.858	*0*
Greece	3.398,8	*1*	1.294,0	*1*	26.617	*1*
Spain	32.722,0	*7*	10.801,0	*7*	242.735	*7*
France	57.894,9	*12*	18.259,9	*11*	323.381	*10*
Croatia	1.363,6	*0*	468,5	*0*	28.823	*1*
Italy	80.308,7	*17*	24.798,3	*16*	453.904	*14*
Cyprus	327,5	*0*	107,8	*0*	3.726	*0*
Latvia	474,9	*0*	125,9	*0*	8.534	*0*
Lithuania	549,6	*0*	157,1	*0*	11.989	*0*
Luxembourg	721,1	*0*	222,1	*0*	3.892	*0*
Hungary	4.235,6	*1*	1.159,4	*1*	64.039	*2*
Malta	95,6	*0*	34,8	*0*	1.428	*0*
Netherlands	20.177,3	*4*	6.101,0	*4*	83.924	*3*
Austria	13.458,0	*3*	4.856,0	*3*	69.333	*2*
Poland	19.370,9	*4*	5.644,5	*4*	251.805	*8*
Portugal	5.662,7	*1*	1.798,3	*1*	77.328	*2*
Romania	3.531,7	*1*	853,7	*1*	86.264	*3*
Slovenia	3.157,5	*1*	847,1	*1*	28.432	*1*
Slovakia	4.005,9	*1*	1.233,4	*1*	40.649	*1*
Finland	6.824,8	*1*	2.322,3	*1*	41.289	*1*
Sweden	14.131,5	*3*	4.943,7	*3*	72.513	*2*
United Kingdom	36.468,4	*8*	14.945,1	*9*	293.342	*9*

1.3. Main environmental aspects and pressures of the Fabricated Metal Product manufacturing sector

1.3.1. Environmental aspects

The Fabricated Metal Product manufacturing sector can be characterized 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 paragraph 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 subsectors. Similar processes and activities are used in the entire Fabricated Metal Products sector, like logistics, utilities, and manufacturing processes (e.g. removing, forming, additive processes). There are no clear indications of important differences between the Fabricated Metal Products 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 sector as a whole.

An overview of the direct and indirect environmental aspects and pressures in the Fabricated Metal Products sector is presented in Figure 7. The **direct environmental aspects** of the sector are mainly related to:

- Product and manufacturing design
- Manufacturing processes:
  - Forming processes
  - Removing processes
  - Additive processes
  - Joining processes
  - Finishing processes
- Supporting processes:
  - Management, procurement, supply chain management, quality control
  - Logistics handling and storage
  - Emissions treatment
  - Utilities and maintenance

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

- Upstream activities:
  - Raw material production
  - Equipment production
- Downstream activities:
  - Assembly
  - Product finishing
  - Protection and packaging
  - Logistics
  - Use phase, disassembly, recycling

By working on a higher organizational level both the **direct *and* indirect environmental aspects** can been reduced). This can be done by focusing on concurrent engineering (see Box 1) and product design. As they encroach deeply on the value chain, this can only succeed when the partners in the value chain work together. The initiative can be taken by one or more partners in the value chain.

Box 1. Organizational and temporal scale of environmental impact reduction approaches – Concurrent Engineering (CE).

Coulter et al. (1995) and Bras (1997) described different environmental impact reduction approaches and classified each approach based on their organizational and temporal concern (see Figure 6).

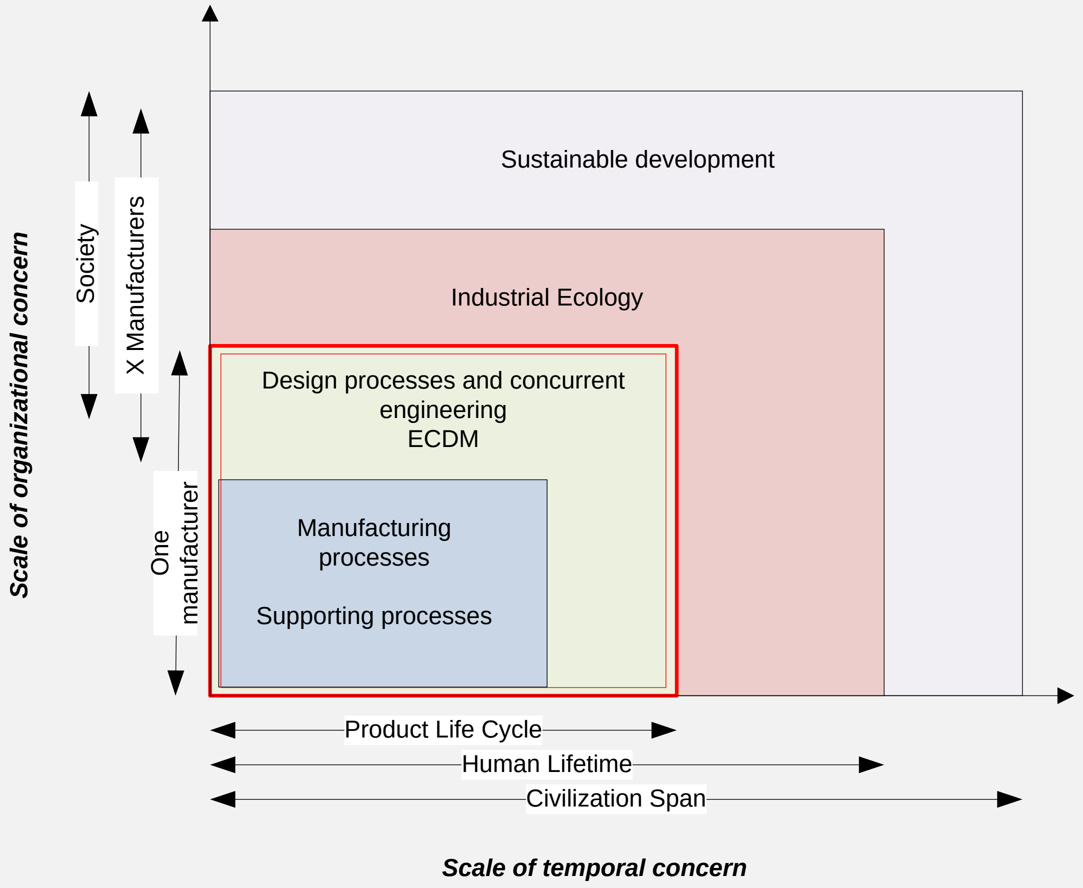


Figure 6. Organizational and temporal scale of environmental impact reduction approaches. Based on Coulter et al. (1995) and Bras (1997). Red line: scope of this study

One of the first definitions for Concurrent Engineering (CE) is given by Winner, et al. (1988), as "a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements". They describe the role of CE for the development of weapons (which is one of the Fabricated Metal Products sectors). Later the concept is taken

over by the European Space Agency (ESA, 2012) as "Concurrent Engineering (CE) is a systematic approach to integrated product development that emphasises the response to customer expectations. It embodies team values of co-operation, trust and sharing in such a manner that decision-making is by consensus, involving all perspectives in parallel, from the beginning of the product life-cycle."

The concept was picked up by Coulter et al. (1995) and Bras (1997), to define Environmentally Conscious Design and Manufacturing (ECDM). The general goal of environmentally conscious approaches to product design is the reduction of the negative environmental impact of a product throughout its life cycle. As shown in Figure 6, ECDM, similar to design for the environment and life cycle design, needs a higher level on organization concern. It needs also a mind shift which takes more time.

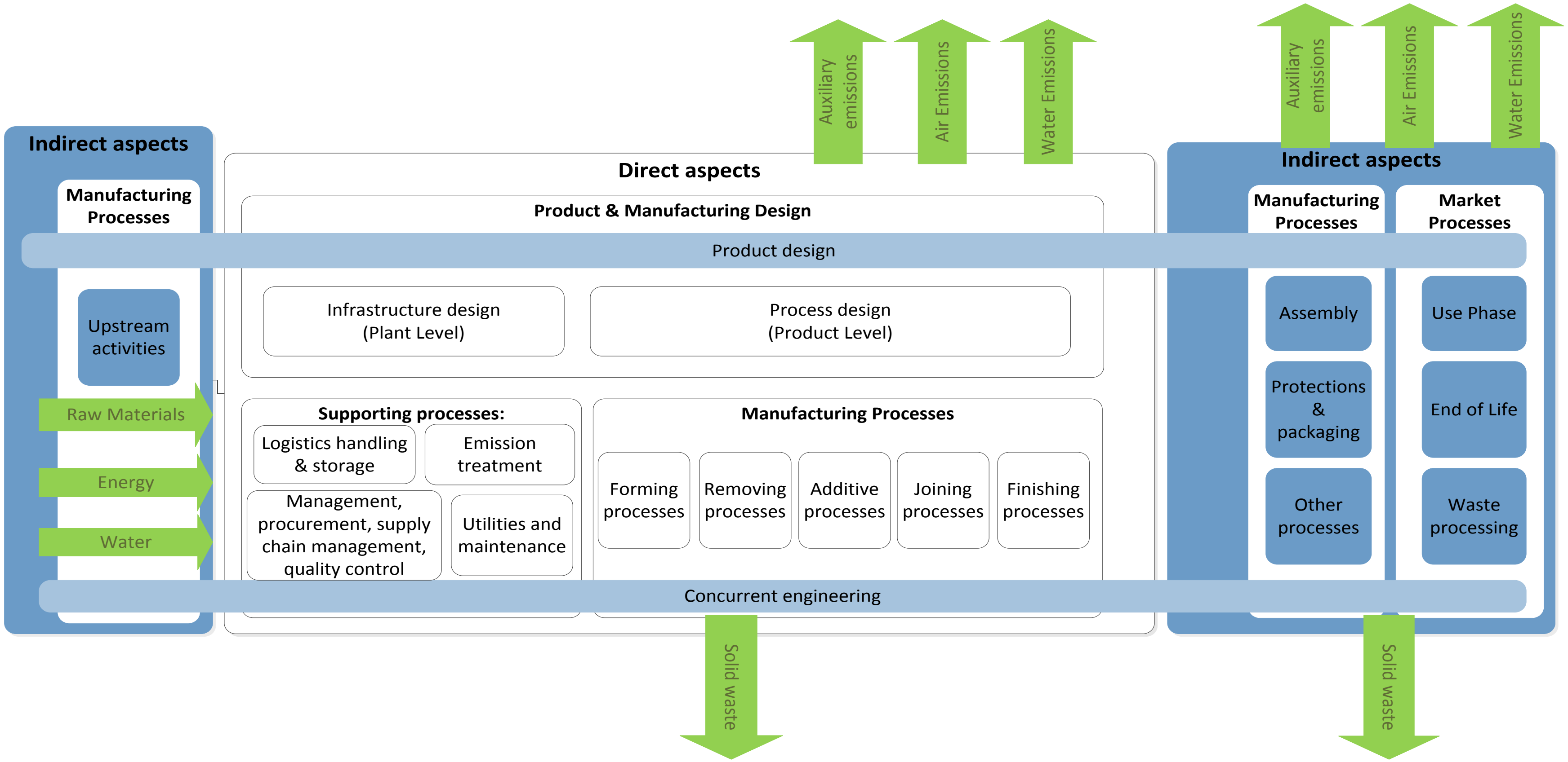


Figure 7. Schematic overview of the direct and indirect aspects and environmental pressures of the Fabricated Metal Products sector

Figure 7 furthermore gives an indication of the main environmental pressures related to the direct and indirect environmental aspects, indicated with the green arrows. However, a more detailed overview and assessment of the environmental pressures is given in section 1.3.2 (Table 4 and Table 5).

1.3.2. Environmental pressures and impacts

The assessment in Table 4 represents to what extent the up- and downstream activities (indirect aspects) are influenced by the activities, products and services of a company in the Fabricated Metal Products sector, ranging from a small to a medium and to a large influence. The categories of the environmental pressures for which this assessment is conducted, consist of:

- Resource use:
  - Raw materials
  - Energy
  - Water
  - Consumables
- Emissions:
  - Water
  - Air
  - Odour
  - Other nuisances (noise, vibration…)
- Waste:
  - Non-hazardous waste
  - Hazardous waste
  - Liquid waste

The interaction between the 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 5, for the direct aspects (Fabricated Metal Products sector) and the interface processes of the indirect aspects. The same categories of environmental pressures are used as in Table 4. The environmental pressures and aspects assessed in Table 5 as medium (++) and large (+++) impact can be considered as main environmental aspects.

Table 4. Influence on indirect environmental pressures by companies in the Fabricated Metal Products sector (NACE 25)

Legend

+	small impact
++	medium impact
+++	large impact
/	not applicable

		Product Life Cycle					
		Concurrent Engineering and Product Design					
		Indirect aspects	**Direct aspects**		**Indirect aspects**	**Direct & Indirect aspects**	
		upstream	**NACE 25 Product & Manufacturing Design**		**down stream**	**value chain**	
		Design Process	**Supporting processes**	**Manufacturing Processes**	**Manufacturing Processes**	**Design Process**	**Market processes**
		- raw material production - production equipment	- Management, procurement, supply chain management, quality control - Logistics handling and storage - Emission treatment - Utilities and maintenance	- Forming processes - Removing processes - Additive processes - Joining processes - Finishing processes - Packaging processes	- Assembly - Product finishing - Protection & Packaging - Logistics	- Material selection	- Use Phase - Refurbishment - Disassembly - Material recycling
Resource use	**Raw Materials**	+++	See Table 5		+	+++	/
	Energy	++			+++	++	/
	Water	+			/	+	/
	Consumables	+			+	++	/
Emissions	**Water**	+	See Table 5		/	/	/
	Air	+			+	/	/
	Odour	/			/	/	/
	Other (noise, vibration, etc.)	+			+	/	+
Waste	**Non hazardous**	++	See Table 5		++	+	++
	Hazardous	+			/	/	+
	Liquid waste	+			+	/	/

Table 5. Assessment of the environmental pressures of the direct aspects (NACE 25) and interface processes of the indirect aspects

Legend	
+	small impact
++	medium impact
+++	large impact
/	not applicable

		Direct aspects									
		Infrastructure design				**Process Design**					
		Supporting processes				**Manufacturing Processes**					
		- Management, procurement, supply chain management, quality control	Logistics, handling and storage	Emission Treatment: - water treatment - air treatment	Utilities and maintenance: - process heating & cooling - compressed air - HVAC building	Forming Processes: - forging - bending	Removing Processes: - turning, milling, - EDM processes - cutting, punching, laser,	Additive processes: - 3D printing	Joining Processes: - welding - brazing	Finishing Processes: - heat treatment - surface treatment electrochemical - laser operations	Packaging
Resource use	**Raw Materials**	+ + +	+	/	/	+ +	+ + +	+ +	+	+	+ +
	Energy	+ +	+	+ +	+ + +	+ +	+ +	+ +	+ +	+ +	/
	Water	+	/	/	+	/	+	/	/	+ + +	/
	Consumables	+ +	+	+	+	/	+ +	/	+ +	+ +	/
Emissions	**Water**	/	/	+ + +	+	/	+	/	/	+ + +	/
	Air	/	+	+	/	/	+	/	+ +	++	/
	Odour	/	/	+	+	/	+	/	+ +	++	/
	Other (noise,)	/	+	+	+ +	+ +	+ +	+	+		/
Waste	**Non hazardous**	+	/	+ +	/	+	+ + +	+	+	+	+ +
	Hazardous	/	/	+	/	/	/	/	/	+ + +	/
	Liquid waste	/	/	/	/	/	+	/	/	+ + +	/

Within the **design processes and concurrent engineering** 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 optimization 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').

Management, procurement, supply chain management and quality control are considered as supporting processes to the manufacturing activities in this study. Although these supporting processes themselves have in general no are very low impact on the environment, they can have a high potential in influencing the environmental impact of the Fabricated Metal Products activities, especially regarding resource use or waste generation. For example, the implementation of an efficient supply chain management system in a company in the 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 Product 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 Product manufacturing activities by improving process steps.

Logistics, handling and storage are not considered in this analysis as a 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 organized and managed by the company itself, by the suppliers or outsourced to a private logistic organization.

Emission treatment, mainly treatment of water and air emissions and of hazardous products, can require a considerable amount of energy. The treatment of emissions is mainly applied and related to the impacts of the (surface) finishing processes in the sector, leading to important emissions of discharged water and non-hazardous waste.

The **utilities** applied in the sector (e.g. heating, cooling, compressed air, HVAC) can require significant energy consumption. Therefore, heat recovery and smart controls can have a high potential in the reduction of energy consumption. 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. In general, the utility department is also responsible for the **maintenance** of the production plant.

As part of the manufacturing processes of the Fabricated Metal Products sector, the **forming processes** mainly consist of forging (forging, pressing, stamping and roll-forming of metal) and bending. The use of raw materials (ferrous and non-ferrous metals) and energy and the emission of noise and/or vibrations are the main environmental pressures related to these aspects. The energy used is mainly electric energy, for thermal processes gas is applied.

Several **removing processes** are widely applied throughout all Fabricated Metal Products 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 …). Cutting, punching and laser cutting are applied in the fabrication of sheet metal and tubing. Most removing processes however are characterized by a high impact on raw material and (electric) energy use. Almost all removed material consists of non-value added material. Therefore, near net shape processes have a high potential. Consumables, such as cooling and lubricating consumables, are widely used in the entire Fabricated Metal Products 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).

Additive processes (3D printing) are processes used in specific Fabricated Metal Products subsectors, making products with high added value and precision (ammunition, other products, etc.). These processes are typically characterized by a considerable impact on the use of raw materials and energy required by the processes.
Thermal **joining processes**, mainly welding and brazing, are generally applied in most 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 **finishing processes** applied in the sector can differ between the various subsectors, depending on the products and applications. Heat treatment processes for example largely differ for ferrous and non-ferrous metals (e.g. hardening and extrusion). Laser processes like engraving and polishing are used for specific high value products. Finishing processes such as 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).

Packaging processes in the Fabricated Metal Products sector have to ensure the quality of the products, e.g. protecting against corrosion at storage and transport.

Packaging processes will mainly have an impact on the use of raw materials (packaging materials) and the production of non-hazardous waste streams.

Similar to the upstream activities, the sector (NACE 25 organisations) can have a significant impact on material effectiveness in the downstream activities through material selection and process selection by **concurrent engineering (product & process)**.
The concept and benefits for improving the environmental performance of Fabricated Metal Products companies will be described under CHAPTER 2 Best environmental management practice.

By using an environmentally extended multi-regional input-output database including highly-detailed national input-output tables (i.e. the EORA database[7]), the direct and indirect environmental impacts of the Fabricated Metal Products sector can be analysed. This database is used to derive direct, indirect and total coefficients. Although EORA uses a slightly different sector classification system than NACE Rev. 2 (see Table 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 6. Comparison of sector classification systems of EORA (UK) and NACE Rev.2

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

[7] Link: www.worldmrio.com

EORA classification (UK)	*NACE Rev.2*
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 sector (NACE 25), e.g. direct emissions of NMVOC and CO2. 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 7 and Figure 8 present an overview of the analysis based on the Eurostat and EORA (UK) database.

Table 7. Direct and total emissions and resource use of the Fabricated Metal Products (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 7, the indirect emissions of the sector can be calculated. Figure 8 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.

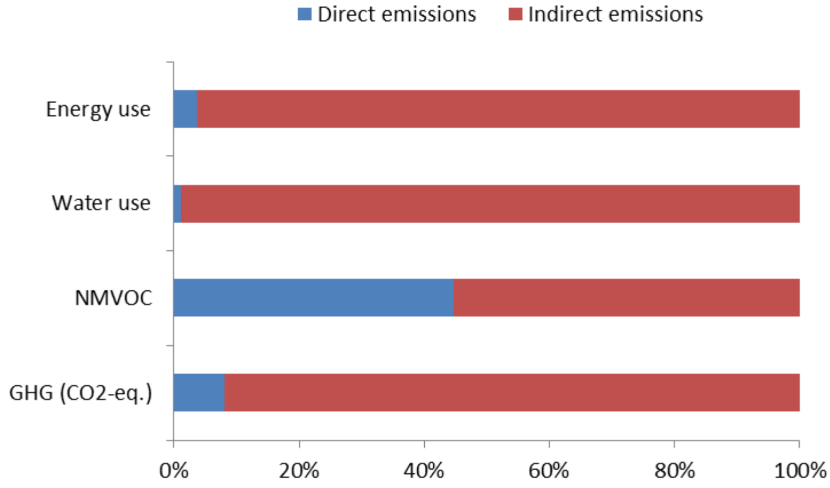


Figure 8. Relative share of direct and indirect emissions of the Fabricated Metal Products sector (EORA, 2011)

Figure 8 clearly 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 sector (NACE 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 Sankey diagrams in Figure 9 and Figure 10 give an overview of the material flows of steel and aluminium respective. The sector (NACE 25) uses metals from founding industry to produce semi-finished products and end-products. However they are not the only sector doing this kind of activities. Below we give an illustrative overview:

- NACE 28: 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.

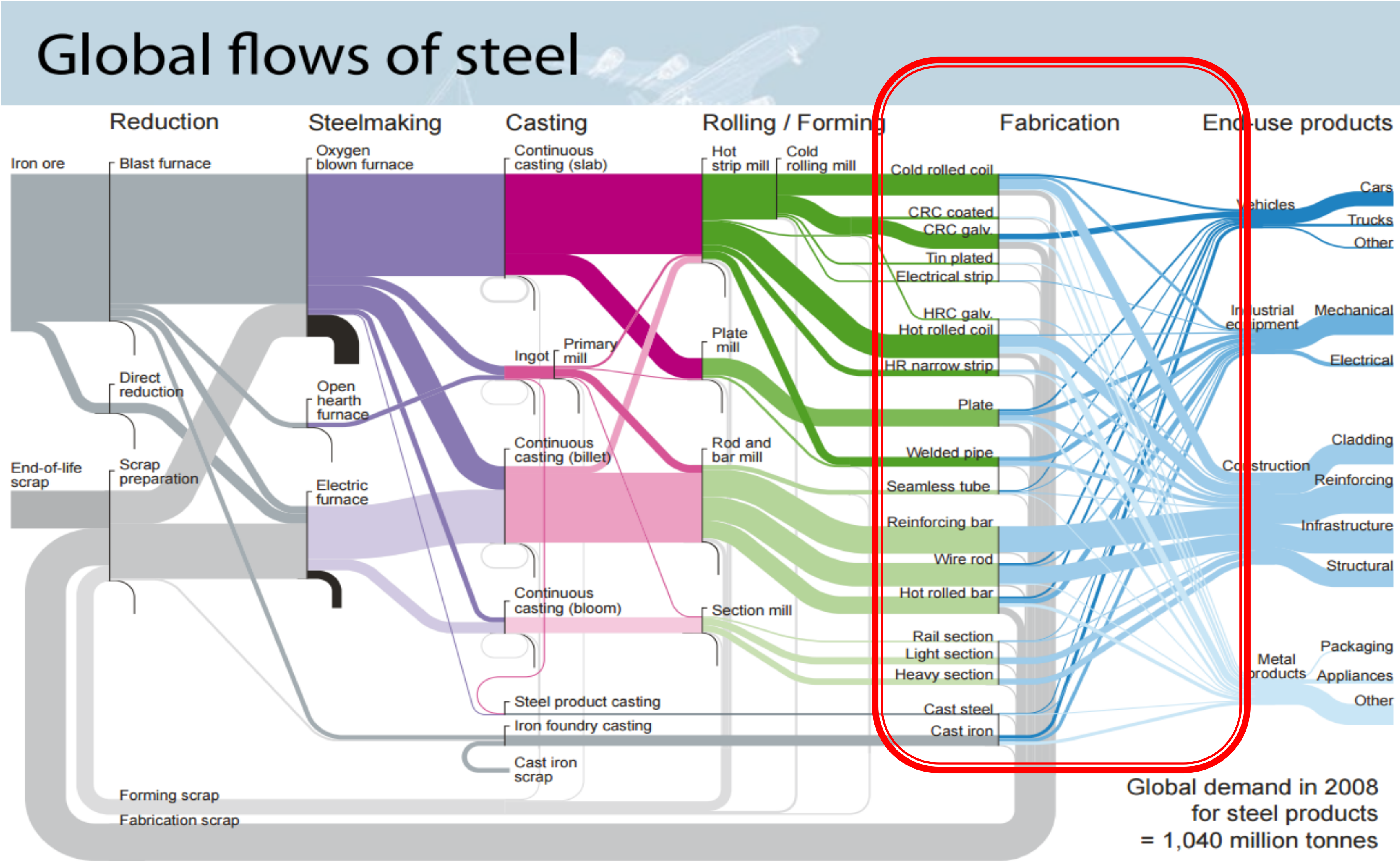


Figure 9. Basis: Sankey diagram of steel flow – the activities of the Fabricated Metal Product manufacturing sector are situated in the green/blue areas (Allwood, 2011); double red line: scope of this study

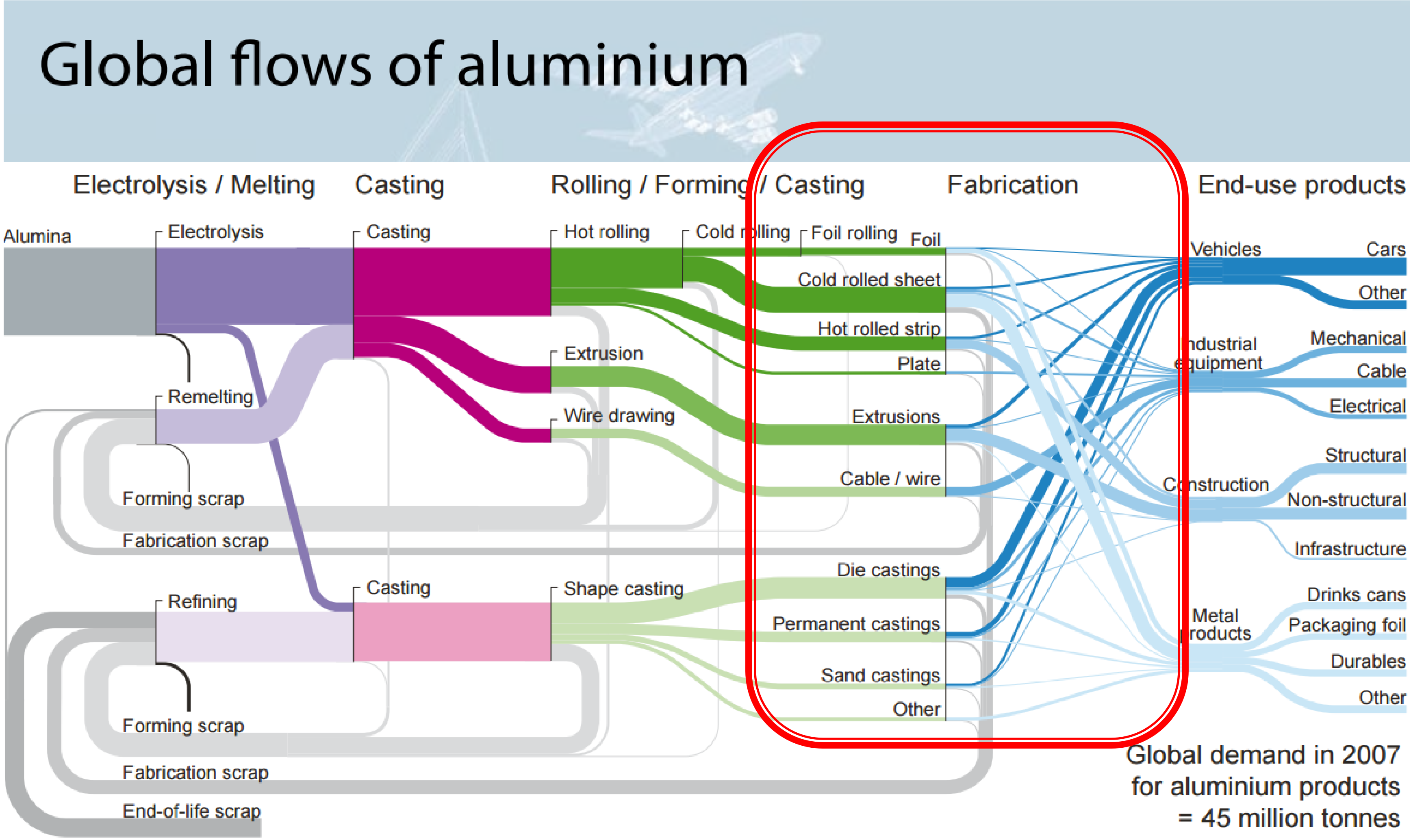


Figure 10. Basis: Sankey diagram of aluminium flow – the activities of the Fabricated Metal Product manufacturing sector are situated in the green/blue areas (Allwood, 2011); double red line: scope of this study

1.4. EMAS and the Fabricated Metal Product manufacturing sector

In the EU-28 there are a total of 95 companies in the Fabricated Metal Product manufacturing sector (NACE division 25) having an EMAS registration. Since some of these companies have 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 Product manufacturing subsectors equals 171 (**Error! Reference source not found.**). The treatment and coating of metals (NACE 25.61) is the class with the highest number of EMAS registrations, followed by the manufacture of metal structures and parts of structures (NACE 25.11), machining (NACE 25.62) and manufacture of other fabricated metal products n.e.c. (NACE 25.99). In Italy 40 EMAS registered organisations are located which is a significantly higher number compared to other EU-28 member states.

Table 8. Overview of EMAS registrations (registration numbers and organisations) in EU-28 in the Fabricated Metal Products sector (http://ec.europa.eu/environment/emas/register/)[8]

NACE code	*AT*	*BG*	*CZ*	*DE*	*DK*	*ES*	*GR*	*HU*	*IT*	*PL*	*PT*	*RO*	*SE*	*UK*	*Total*
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
25.94	1			5									1		7
25.99	1			6		1	1		5				1		15
Total	**6**	**1**	**10**	**71**	**1**	**15**	**3**	**3**	**48**	**1**	**5**	**1**	**5**	**1**	**171**
Number of companies	*5*	*1*	*6*	*17*	*1*	*12*	*2*	*3*	*40*	*1*	*4*	*1*	*1*	*1*	*95*

[8] 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 10/03/15).

1.5. EU legislation, policy instruments and best practice guidance

Processes and environmental aspects of the NACE 25 (sub)sectors that are covered by one of the BREFs, directly or indirectly linked to the manufacture of fabricated metal products as well as by EU legislation, policy instruments and best practice guidance are excluded from the scope of this study (see Figure 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. Table 9 gives an overview of the BREFs directly or indirectly linked to the manufacture of fabricated metal products. Besides the reference to annex I of the IED, a short description is given of the processes / activities as well as the techniques and environmental aspects within scope of BREF. Further, the table contains the link to Fabricated Metal Products by referring to the processes as outlined in paragraph 1.3.

The BREFs STM and STS are the most direct linked to the Fabricated Metal Products value chain. As the case for the installations under de scope of these BREFs, besides large installations, most of the Fabricated Metal Product manufacturing installations are small or medium sized (Eurostat 2011 and 2012).

The surface treatment of metals and plastics is carried out in Europe in more than 18300 installations, both IPPC and non-IPPC. The sector is composed of small private companies as well as facilities owned by multinational corporations. The large majority are small or medium enterprises[9] (BREF STM). More than 55% are specialist surface

9 EU recommendation 2003/361:

Medium-sized: <250 employees and ≤ € 50 m (turnover) or ≤ € 43 m (balance sheet total)

treatment installations. The remaining 45% are surface treatment shops within another installation typically also an SME. Surface treatment using solvents is carried out in more than 500000 companies (EU-25, IPPC as well as non-IPPC). Most of these companies are also SMEs (BREF STS).

Small: <50 employees and ≤ € 10 m (turnover) or ≤ € 10 m (balance sheet total)

Table 9. Global overview of processes/activities/techniques within the scope of BREFs (directly or indirectly) linked to the manufacture of Fabricated Metal Products

BREF	*Scope BREF (IED, annex 1)*	*Global overview of processes / activities within scope of BREFs*	*Techniques and environmental aspects within scope of BREFs*	*Link to Fabricated Metal Products value chain (see Figure 7)*
Surface Treatment of Metals and Plastics (BREF STM, August 2006)	**2.6.** Installations for surface treatment of metals and plastic materials using an electrolytic or chemical process where the volume of the treatment vats exceeds 30 m³	- water-based electrolytic or chemical processes - surface treatment of metals, barrel processing, continuous coil-large scale steel, sheet processing for aluminium lithography plates, printed circuit board manufacturing	- apply environmental management tools (general aspects) - optimize design, construction and operation of installation to prevent and control unplanned releases, and to prevent soil and groundwater contamination - apply general operational issues to reduce the amount of processing required and the consequent consumptions and emissions - optimize utility inputs and their management to optimize electricity consumption and the amount of energy and/or water used in cooling, and to reduce fuels (used for heating) and heat losses - reduce and control drag-out - optimize raw material usage - optimize electrode techniques - use less hazardous substances by substitution - optimize maintenance: removal	**Covered:** Direct aspects of - finishing processes, in particular water-based electrolytic or chemical processes (all aspects) Direct aspects (in general) of supporting processes: - logistics, handling, storage - emission treatment (water and air) - utilities

BREF	*Scope BREF (IED, annex 1)*	*Global overview of processes / activities within scope of BREFs*	*Techniques and environmental aspects within scope of BREFs*	*Link to Fabricated Metal Products value chain (see Figure 7)*
			of contaminants - optimize process metals recovery (in conjunction with drag-out controls) - apply post-treatment activities, including drying and de-embrittlement - optimize treatment of air emissions - optimize treatment of waste water emissions - optimize waste management (drag-out control and maintenance) - apply noise management: good practice and/or engineered techniques	
Surface Treatment using Organic Solvents (BREF STS, August 2007)	**6.7.** Installations for the surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting,	- organic solvent based surface treatment processes (activities also regulated by the Solvent Emissions Directive, 1999/13/EC) - printing processes using solvents on a large scale: headset web offset, flexible packaging and	- optimize installation design, construction and operation to minimize consumptions and emissions (particularly to soil, water and groundwater, as well as to air) - monitor solvent emissions in order to minimize air emissions - reduce water consumption and/or conserve raw materials in water-based treatment processes	**Covered:** Direct aspects of - finishing processes, in particular organic solvent based surface treatment processes (all aspects) Direct aspects (in general) of supporting processes: - logistics, handling, storage

BREF	*Scope BREF (IED, annex 1)*	*Global overview of processes / activities within scope of BREFs*	*Techniques and environmental aspects within scope of BREFs*	*Link to Fabricated Metal Products value chain (see Figure 7)*
	cleaning or impregnating, with a consumption capacity of more than 150 kg per hour or more than 200 tonnes per year	publication gravure - coating and/or painting of winding wires, wars and commercial vehicles, buses, trains, agricultural equipment, ships and yachts, aircraft, steel and aluminium coil, metal packaging, furniture and wood, and other metal and plastic surfaces - adhesive application in the manufacture of abrasives and adhesive tapes - wood impregnation with preservatives - with these activities associated cleaning and degreasing activities	- minimize energy usage - optimize raw material management - optimize systems for surface treatment, application and drying/curing - optimize cleaning - use less hazardous substances (substitution of solvent-based coatings by water-soluble alternatives) - optimize treatment of emissions to air and waste gas - minimize particulates discharged to air from paint spraying - optimize treatment of waste water - optimize materials recovery and waste management - prevent odour and noise nuisance	- emission treatment: emissions to water and air - utilities
Ferrous Metals Processing Industry (BREF FMP, December 2001)	**2.2.** Installations for the production of pig iron or steel (primary or secondary fusion)	- production of ferrous metals - hot and cold forming (rolling and drawing of steel)	- optimize thermal efficiency and reduce NOx emissions of furnaces - optimize cleaning and reuse, treatment and abatement of oil emulsions	**Covered:** Direct aspects of - upstream activities: raw material production (all aspects)

BREF	*Scope BREF (IED, annex 1)*	*Global overview of processes / activities within scope of BREFs*	*Techniques and environmental aspects within scope of BREFs*	*Link to Fabricated Metal Products value chain (see Figure 7)*
	including continuous casting, with a capacity exceeding 2,5 tonnes per hour **2.3.** Installations for the processing of ferrous metals: (a) hot-rolling mills with a capacity exceeding 20 tonnes of crude steel per hour (b) smitheries with hammers the energy of which exceeds 50 kilojoule per hammer, where the calorific power used exceeds 20 MW (c) application of protective fused metal coats with an input exceeding 2 tonnes of crude steel per hour **2.4.** Ferrous metal	- continuous hot dip coating - batch galvanizing	- optimize alkaline degreasing, pickling, heating, fluxing, rinsing - optimize treatment of process water and waste water emissions	

BREF	*Scope BREF (IED, annex 1)*	*Global overview of processes / activities within scope of BREFs*	*Techniques and environmental aspects within scope of BREFs*	*Link to Fabricated Metal Products value chain (see Figure 7)*
	foundries with a production capacity exceeding 20 tonnes per day			
Non Ferrous Metals Industries (BREF NFM, December 2001)	2. Production and processing of metals **2.1.** Metal ore (including sulphide ore) roasting or sintering installations **2.5.** Installations: (a) for the production of non-ferrous crude metals from ore, concentrates or secondary raw materials by metallurgical, chemical or electrolytic processes (b) for the smelting, including the alloyage, of non-ferrous metals, including recovered products, (refining,	- production of primary and secondary non-ferrous metals: - copper (including Sn and Be) and its alloys - aluminium - zinc, lead and cadmium, (+ Sb, Bi, In, Ge, Ga, As, Se, Te) - precious metals - mercury - refractory metals - ferro alloys - alkali and alkaline earth metals - nickel and cobalt. - carbon and graphite	- reduce emissions to air (e.g. SO_2, dust, metal compounds, organic compounds, fluorides (incl. HF), VOCs (including dioxins), odours) and waste water (e.g. metal and organic compounds) - minimize process residues and waste	**Covered:** Direct aspects of - upstream activities: raw material production (all aspects)

BREF	*Scope BREF (IED, annex 1)*	*Global overview of processes / activities within scope of BREFs*	*Techniques and environmental aspects within scope of BREFs*	*Link to Fabricated Metal Products value chain (see Figure 7)*
	foundry casting, etc.) with a melting capacity exceeding 4 tonnes per day for lead and cadmium or 20 tonnes per day for all other metals **6.8.** Installations for the production of carbon (hard-burnt coal) or electrographite by means of incineration or graphitization			
Smitheries and Foundries Industry (BREF SF)		-processing of ferrous metals as smitheries -ferrous metal foundries -smelting, including the alloyage, of non-ferrous metals, including recovered products (refining, foundry casting, etc.). The following foundry process steps are covered: • pattern making	-prevention of soil and water pollution and optimization of the internal recycling of scrap metal -optimization of the furnace efficiency and minimisation of residue production -minimizing consumptions -reduction of VOCs and odour emissions -reduction of (fugitive) emissions -energy efficiency -regeneration or re-use of sand (auxiliary) -dust and solid residues: treatment	Indirect aspects upstream Design Process

BREF	*Scope BREF (IED, annex 1)*	*Global overview of processes / activities within scope of BREFs*	*Techniques and environmental aspects within scope of BREFs*	*Link to Fabricated Metal Products value chain (see Figure 7)*
		• storage and handling of raw materials • melting and metal treatment • mould and core production, and moulding techniques • casting or pouring and cooling • shake-out • finishing • heat treatment	and re-use -noise reduction -prevent pollution at the decommissioning stage. -environmental management tools	
Energy Efficiency (BREF ENE, February 2009)	all IPPC installations	- guidelines for energy efficiency	- optimize energy efficiency - minimize energy use - minimize air emissions	**Covered:** Direct aspects (in general) of - utilities: energy use; air emissions
Industrial Cooling Systems (BREF ICS, December 2001)	all IPPC installations	- cooling systems that are considered to work as auxiliary systems for the normal operation of an industrial process	- optimize cooling - minimize the use of water, energy, consumables - minimize emissions to water and air	**Covered:** Direct aspects (in general) of - utilities: use of water, energy, consumables; emissions to water and air
Large Combustion Plants (BREF LCP, May 2005)	all combustion installations with a rated thermal input exceeding 50 MW	- power generation industry - combustion plants working on conventional fuels (e.g. coal, lignite,	- optimize combustion - minimize energy use - minimize air emissions	**Covered:** Direct aspects (in general) of - utilities: use of energy; emissions to air

BREF	*Scope BREF (IED, annex 1)*	*Global overview of processes / activities within scope of BREFs*	*Techniques and environmental aspects within scope of BREFs*	*Link to Fabricated Metal Products value chain (see Figure 7)*
		biomass, peat, liquid and gaseous fuels, including hydrogen and biogas) not covered within another sector BREF. - co-combustion of waste and recovered fuel in large combustion plants - upstream and downstream activities directly associated to the combustion process		
Waste Treatment Industries (BREF WT, August 2006)	**5.1** Disposal or recovery of hazardous waste with a capacity exceeding 10 tonnes per day … **5.3** (a) Disposal of non-hazardous waste with a capacity exceeding 50 tonnes per day (b) Recovery, or a mix of recovery and	- management of hazardous and non-hazardous waste	- optimize temporary storage of waste, blending and mixing, repackaging, waste reception, sampling, checking and analysis, waste transfer and handling installations, and waste transfer stations - optimize mechanical, physico-chemical and biological treatments of liquid waste - optimize waste recovery (e.g. reconcentration of acids and bases, recovery of metals from liquid and solid photographic waste,	**Covered:** Direct aspects of - downstream activities: treatment of hazardous and non-hazardous waste

BREF	*Scope BREF (IED, annex 1)*	*Global overview of processes / activities within scope of BREFs*	*Techniques and environmental aspects within scope of BREFs*	*Link to Fabricated Metal Products value chain (see Figure 7)*
	disposal, of non-hazardous waste with a capacity exceeding 75 tonnes per day … **5.5** Temporary storage of hazardous waste not covered under point 5.4 pending any of the activities listed in points 5.1, 5.2, 5.4 and 5.6 with a total capacity exceeding 50 tonnes, excluding temporary storage, pending collection, on the site where the waste is generated		regeneration of organic solvents and spent ion exchange resins, and re-refining of waste oils) - optimize the production of solid and liquid fuels from hazardous and non-hazardous waste	
Waste Incineration (BREF WI, August 2006)	**5.2** Disposal or recovery of waste in waste incineration plants or in waste co-incineration plants: (a) for non-hazardous waste with a capacity	- incineration, pyrolysis and gasification of hazardous and municipal waste	- optimize reception, handling and storage of waste - optimize waste pre-treatment - optimize flue-gas treatment - optimize waste water treatment - optimize energy recovery	Direct aspects of - downstream activities: treatment of hazardous and non-hazardous waste

BREF	*Scope BREF (IED, annex 1)*	*Global overview of processes / activities within scope of BREFs*	*Techniques and environmental aspects within scope of BREFs*	*Link to Fabricated Metal Products value chain (see Figure 7)*
	exceeding 3 tonnes per hour; (b) for hazardous waste with a capacity exceeding 10 tonnes per day.			

As indicated in Table 9 some direct environmental aspects from Fabricated Metal Product manufacturing installations are already covered by BREFs under the IED. Some examples of direct environmental parameters from manufacturing installations already covered by BREFs are given in Table 10.

Table 10. Examples of direct environmental parameters covered in the BREFs (directly or indirectly) linked to the manufacture of Fabricated Metal Products

BREF	*environmental issues covered in the BREFs*	*Parameters*
Industrial processes & related operations leading to BAT-AELs[10]	emission into water	metals, surfactants (NPE and PFOS), complexing agents (cyanides and EDTA), chlorides, sulphates, phosphates, nitrates and anions
	air emissions	NOx, HCl, HF, acid particulates, hexavalent chromium mist, ammonia, dust and solvents
Industrial processes & related operations NOT leading to BAT-AELs[11]	energy	energy consumption
	consumables	use of chemicals for cleaning
	water	water consumption
	raw materials	usage of raw materials
	waste	occurrence of solid and liquid wastes

EU legislation, policy instruments and best practice guidance

As already described above, some processes and direct environmental aspects from Fabricated Metal Product manufacturing installations are already covered by BREFs under the IED. Table 11 gives an overview of the EU legislation, policy instruments and best practice guidance relevant for products and processes of the NACE 25 (sub)sectors. The tables include also a short description of the field of application. Further a link is made to the processes and environmental aspects as outlined in paragraph 1.3.

[10] Best Available Technique Associated Emission Level

[11] E.g. water performancy levels, material efficiency levels, solvent re-using levels.

Table 11. Overview of the EU legislation, policy instruments and best practice guidance relevant for products and processes of the NACE 25 (sub)sectors

environmental issues	*reference*	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see paragraph 1.3)*	*link with environmental parameters*
GENERAL	Industrial Emissions Directive (IED, 2010/75/EU)[12]	IPPC installations - BREFs The European Union (EU) defines the obligations to be met by industrial activities with a major pollution potential. It establishes a permit procedure and lays down requirements, in particular with regard to discharges. The objective is to avoid or minimize polluting emissions in the atmosphere, water and soil, as well as waste from industrial and agricultural installations, with the aim of achieving a high level of environmental and health protection.	http://eippcb.jrc.ec.europa.eu/index.html	manufacturing processes (all)	resource use (all), emissions (all), waste (all)

[12] DIRECTIVE 2010/75/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (integrated pollution prevention and control)

environmental issues	*reference*	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see paragraph 1.3)*	*link with environmental parameters*
ENERGY	Directive 2012/27/EU[13] Energy efficiency directive	This directive covers various measures to improve the overall European energy efficiency and defines some concrete obligations for industry: enterprises that are not SMEs are subject to an energy audit by 5 December 2015 and at least every four years AND new or substantially refurbished thermal electricity generation installation with a total thermal input exceeding 20 MW should carry out a cost-benefit analysis application of high-efficiency cogeneration and/or efficient district heating and cooling	http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0027&from=EN	supporting processes - process heating and cooling (not for SMEs and existing thermal electricity generation installations)	energy efficiency cogeneration heating cooling
WATER	Directive 2000/60/EC[14] Water framework	This framework-Directive has several objectives such as preventing and reducing pollution, promoting sustainable water usage, protecting the	http://ec.europa.eu/environment/water/water-framework/index_en.html	finishing processes - surface treatment	water (use / discharge)

[13] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

[14] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

environmental issues	*reference*	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see paragraph 1.3)*	*link with environmental parameters*
	directive	environment, improving the state of aquatic eco-systems and reducing the effects of floods and droughts.			
CONSUMABLES	REACH 1907/2006 [15]	REACH is a regulation of the EU, adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals, while enhancing the competitiveness of the EU chemicals industry. It also promotes alternative methods for the hazard assessment of substances in order to reduce the number of tests on animals.	http://echa.europa.eu/regulations/reach	manufacturing processes (removing, joining, finishing processes)	resource use (all)
emissions to WATER	2000/60/EC [16]	This framework-Directive has several objectives such as preventing and reducing pollution, promoting sustainable water usage, protecting the environment, improving the state	http://ec.europa.eu/environment/water/water-framework/index_en.html	finishing processes - surface treatment supporting processes - wastewater treatment	water (use / discharge)

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

[16] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

environmental issues	*reference*	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see paragraph 1.3)*	*link with environmental parameters*
		of aquatic eco-systems and reducing the effects of floods and droughts.			
	2008/105/EC [17]	This Directive sets out environmental quality standards (EQS) concerning the presence in surface water of certain substances or groups of substances identified as priority pollutants on account of the substantial risk they pose to or via the aquatic environment The EQS in Directive 2008/105/EC are limits on the concentration of the priority substances and eight other pollutants in water (or biota), i.e. thresholds which must not be exceeded if good chemical status is to be met	Directive 2008/105/EC - EUR-Lex - Europa	finishing processes - surface treatment supporting processes - wastewater treatment	water (discharge)

[17] Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC

environmental issues	*reference*	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see paragraph 1.3)*	*link with environmental parameters*
	2006/118/EC[18]	This Directive is designed to prevent and combat groundwater pollution. Its provisions include: - criteria for assessing the chemical status of groundwater - criteria for identifying significant and sustained upward trends in groundwater pollution levels, and for defining starting points for reversing these trends - preventing and limiting indirect discharges (after percolation through soil or subsoil) of pollutants into groundwater	http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32006L0118	finishing processes - surface treatment supporting processes - wastewater treatment	water (discharge)
emissions to AIR	2001/379/EC[19]	The aim of the Protocol is to reduce emissions from heavy metals caused by anthropogenic activities that are subject to long-range transboundary atmospheric transport and are likely to have serious adverse effects on human health and the environment. To this end, it	http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32001D0379	manufacturing processes	air (emission of heavy metals)

[18] Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration

[19] Council Decision 2001/379/EC of 4 April 2001 on the approval, on behalf of the European Community, of the Protocol to the 1979 Convention on Long-range Transboundary Air Pollution on Heavy Metals

environmental issues	*reference*	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see paragraph 1.3)*	*link with environmental parameters*
		stipulates the reduction of total annual emissions into the atmosphere of cadmium, lead and mercury, and the application of product control measures.			
	2001/81/EC[20]	This Directive covers emissions in the territory of the Member States and their exclusive economic zones from four pollutants which arise as a result of human activities: SO_2, NOx, VOC, NH_3	http://eur-lex.europa.eu/legal-content/NL/TXT/?uri=CELEX:32001L0081	manufacturing processes	air (emissions of sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia)
	2003/87/EC[21]	This European emission trading system (ETS) is the key measure in European climate policy. It covers more than 10.000 installations of energy-intensive industry and electricity sector that are responsible for almost have of CO2-emissions in the EU.	http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02003L0087-20140430	manufacturing processes	emission of greenhouse gases

[20] Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants

[21] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC

environmental issues	*reference*	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see paragraph 1.3)*	*link with environmental parameters*
		A company within the scope of ETS (>3MW, listed in activities of annex 1) needs to monitor and report annually the CO2 emissions and is obliged to hand in an amount of emission rights corresponding with the amount of CO2- emissions of the previous year			
NOISE	2000/14/EC[22]	This framework Directive harmonises the 9 existing legal instruments on noise emissions for each type of construction plant and equipment, as well as a directive on lawnmowers. The aim is to improve the control of noise emissions by more than 50 types of equipment used outdoors, such as compressors, excavator-loaders, different types of saws, mixers, etc. (Annex I).	http://eur-lex.europa.eu/legal-content/NL/TXT/?uri=celex:32000L0014	use phase	noise

[22] Directive 2000/14/EC of the European Parliament and of the Council of 8 May 2000 on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors

environmental issues	*reference*	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see paragraph 1.3)*	*link with environmental parameters*
WASTE	Waste Framework Directive (2008/98/EC[23])	This Directive repealed Directive 2006/12/EC of the European Parliament and of the Council of 5 April 2006 on waste (the codified version of Directive 75/442/EEC as amended), hazardous waste Directive 91/689/EEC, and the Waste Oils Directive 75/439/EEC. It provides for a general framework of waste management requirements and sets the basic waste management definitions for the EU	http://ec.europa.eu/environment/waste/legislation/a.htm	process design - manufacturing processes (all)	waste (hazardous / non-hazardous)
	WEEE (2012/19/EU[24])	This Directive lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste from electrical and electronic equipment (WEEE) and by reducing overall impacts of	http://ec.europa.eu/environment/waste/weee/legis_en.htm	market processes - material recycling	waste (hazardous / non-hazardous)

[23] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

[24] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE)

environmental issues	*reference*	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see paragraph 1.3)*	*link with environmental parameters*
		resource use and improving the efficiency of such use in accordance with Articles 1 and 4 of Directive 2008/98/EC, thereby contributing to sustainable development			
	2002/95/EC[25]	The purpose of this Directive is to approximate the laws of the Member States on the restrictions of the use of hazardous substances in electrical and electronic equipment and to contribute to the protection of human health and the environmentally sound recovery and disposal of waste electrical and electronic equipment.	http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0095	upstream activities	waste (hazardous)

[25] Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (ROHS)

environmental issues	*reference*	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see paragraph 1.3)*	*link with environmental parameters*
	94/62/EC[26]	This Directive provides for measures aimed at limiting the production of packaging waste and promoting recycling, re-use and other forms of waste recovery. Their final disposal should be considered as a last resort solution. This Directive covers all packaging placed on the European market and all packaging waste, whether it is used or released at industrial, commercial, office, shop, service, household or any other level, regardless of the material used.	http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31994L0062	downstream manufacturing	waste (protection packaging)
	850/2004/EC[27]	The objective of this Regulation is to protect human health and the environment from persistent organic pollutants by prohibiting, phasing out as soon as possible, or restricting the production, placing on the market and use of substances subject to the Stockholm Convention on	http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32004R0850&qid=1425293945113	manufacturing processes	waste (hazardous)

[26] Directive 94/62/EC of the European Parliament and Council of 20 December 1994 on packaging and packaging waste

[27] Regulation (EC) No 850/2004 of the European Parliament and of the Council of 29 April 2004 on persistent organic pollutants and amending Directive 79/117/EEC

environmental issues	*reference*	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see paragraph 1.3)*	*link with environmental parameters*
		Persistent Organic Pollutants, or the 1998 Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on Persistent Organic Pollutants, and by minimizing, with a view to eliminating where feasible as soon as possible, releases of such substances, and by establishing provisions regarding waste consisting of, containing or contaminated by any of these substances.			
	333/2011/ EC	The criteria determining when iron, steel and aluminium scrap cease to be waste should ensure that iron, steel and aluminium scrap resulting from a recovery operation meet the technical requirements of the metal producing industry, comply with existing legislation and standards applicable to products and do not lead to overall adverse environmental or human health impacts.	http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32011R0333&qid=1424856134440	manufacturing processes	waste

Remark

EU legislation regarding the environmental aspects RAW MATERIALS and ODOUR linked to the NACE 25 subsectors was not found.

Table 12. Overview of the policy instruments relevant for products and processes of the NACE 25 (sub)sectors

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
OSPAR Recommendation 98/1 concerning Best Available Techniques and Best Environmental Practice for the Primary Non-Ferrous Metal Industry (Zinc, Copper, Lead and Nickel Works)	This Recommendation applies to the primary metallurgical industry producing one or more of the following metals or process related compounds: zinc, copper, lead or nickel.	http://rod.eionet.europa.eu/obligations/584	upstream activities - raw material production supporting processes - air / wastewater treatment	air / water raw materials	BREF NFM
OSPAR Recommendation 98/2 on Emission and Discharge Limit Values for Existing Aluminium Electrolysis Plants	This Recommendation covers emissions and discharges from existing aluminium electrolysis plants, but does not apply to anode baking operations.	http://www.ospar.org/v_measures/browse.asp?menu=01070304570124_000001_000000	upstream activities - raw material production	air (PAH & fluorides), water (PAH)	BREF NFM
PARCOM Recommendation 96/1 on Best Available Techniques and Best Environmental Practice for Existing Aluminium Electrolysis Plants	This Recommendation covers emissions and discharges from the aluminium electrolysis process, limited to pot-room operations. This Recommendation applies to existing plants only.	http://rod.eionet.europa.eu/obligations/480	upstream activities - raw material production	raw materials	BREF NFM

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
PARCOM Recommendation 94/1 on Best Available Techniques for New Aluminium Electrolysis Plants	The objective of this Recommendation prevents pollution of the environment, arising from emissions of gaseous and liquid pollutants from aluminium electrolysis in new installations, also accounting for human health.	http://rod.eionet.europa.eu/obligations/498	upstream activities - raw material production supporting processes - air	PAH & fluorides	BREF NFM
PARCOM Decision 96/1 on the Phasing-Out of the Use of Hexachloroethane in the Non-Ferrous Metal Industry	All uses of HCE in the aluminium industry (including integrated and non-integrated foundries casting aluminium) shall be phased out as far as possible by 31 December 1996 and at the latest by 31 December 1997. All uses of HCE in other non-ferrous metal industry shall be phased out by 31 December 1997	http://www.ospar.org/v_measures/browse.asp?menu=01070304570124_000001_000000	upstream activities - raw material production	raw materials	BREF NFM

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
PARCOM Recommendation 92/1 on best available technology for plants producing anodes and for new electrolysis installations in the primary aluminium industry	Best Available Technology in new electrolysis plants and in existing plants which increase capacity by installing new cells, should be based on the use of pre-baked anodes	http://www.ospar.org/v_measures/browse.asp?menu=01070304570124_000001_000000	upstream activities - raw material production	raw materials	BREF NFM
PARCOM Recommendation 92/2 Concerning Limitation of Pollution from New Primary Iron and Steel Production Installations	The recommendation applies for new and substantially modified primary iron and steel production installations that have been granted a building licence after 1 January 1993. The recommendation contains two general requirements. For processes where this general approach should be either specified or modified, separate requirements are given.	http://rod.eionet.europa.eu/obligations/469	upstream activities - raw material production	raw materials	BREF FMP

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
PARCOM Recommendation 92/3 Concerning Limitation of Pollution from New Secondary Steel Production and Rolling Mills	EQS to water (suspended solids, oil, metals) for continuous casting and hot rolling & air	http://rod.eionet.europa.eu/obligations/496	upstream activities - raw material production	raw materials	BREF FMP
OSPAR Recommendation 2002/1 on Discharge Limit Values for Existing Aluminium Electrolysis Plants	This Recommendation covers discharges to water from existing aluminium electrolysis plants and does not apply to anode-baking operations. This Recommendation supplements OSPAR Recommendation 98/2	http://rod.eionet.europa.eu/obligations/489	upstream activities - raw material production	water (discharge) - 6 PAH components (Fluoranthene, Benzo(k)fluoranthene, Benzo(b)fluoranthene, Indeno(1,2,3-cd)pyrene, Benzo(a)pyrene, Benzo(ghi)perylene)	BREF STM
PARCOM Recommendation 84/2 for reducing cadmium pollution	Reducing cadmium from electroplating	http://www.ospar.org/v_measures/browse.asp?menu=01070304570124_000001_000000		outdated - very general recommendations	BREF STM

Table 13. Overview of the best practice guidance relevant for products and processes of the NACE 25 (sub)sectors

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
Best practices for planning in the metals industry	A high level of inefficiency is related to the production planning processes in the metals industry. Low asset utilization, poor delivery performance and high inventory carryover are the three key areas of inefficiency. Corresponding Key Performance Indicators in these three areas are typically used in order to measure and improve production planning performance.	http://www.optimalcore.com/the-core-blog/58-best-practices-for-planning-in-the-metals-industry.html	logistics, handling and storage	resource use; emissions	BREF STM
Best Practices for Fabricated Metals	Developed for small and midsize companies to implement a solution quickly and easily; Production planning and control, Materials management, Sales and distribution, Logistics General QM/PLM, Accounting, Controlling, Master Data Generation,	(hard copy)	logistics, handling and storage	resource use; emissions	BREF STM

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
	Forms and reporting, Non-Ferrous Metal Pricing in DIMP system				
The Surface Treatment of Metals and Plastics by Electrolytic and Chemical Processes (EPR 2.07)	sector guidance note (will be reviewed in the light of future BREF note revisions)		finishing processes - surface treatment	resource use (all), emissions (all), waste (all)	BREF STM
Metalworking Fluids: Safety and Health Best Practices Manual	This document on best practices was developed using the recommendations set forth in the OSHA Metalworking Fluids Standards Advisory Committee Final Report (1999); the NIOSH Criteria Document on Occupational Exposure to Metalworking Fluids (1998); and the Organization Resources Counsellors, "Management of the Metal Removal Fluid Environment: A Guide	https://www.osha.gov/SLTC/metalworkingfluids/metalworkingfluids_manual.html	supporting processes - manufacturing processes	consumables / chemicals	

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
	to the Safe and Efficient Use of Metal Removal Fluids" (1999)				
MIG Welding Aluminium: Important Questions and Best Practices	- filler metal selection - filler metal storage - wire feeding options - short-circuit, spray transfer or pulsed MIG	http://www.millerwelds.com/resources/articles/MIG-GMAW-Effective-on-Aluminum/	raw materials	consumables	
Sector Specific Best Practice Guide Best Practices in metal plating and finishing	This guide is aimed at the smaller metal finishers and mainly focuses on environmental best practices that are relatively simple and straightforward to implement in an existing facility. Therefore some of the more expensive best practice options (e.g., electrodialysis to concentrate drag-out; ultrafiltration for process bath maintenance, etc.) have been omitted from this	http://envirocentre.ie/Content.aspx?ID=97861425-c328-4b1b-aa3f-472ca8e3d759&PID=a257bece-c1e7-464a-9cd0-fde10d3a18c3#Metal	finishing processes - surface treatment	resource use (all), emissions (all), waste (all)	BREF STM

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
	guide.				
Guide to good manufacturing and hygiene practices for metal packaging in contact with food	This guide of recommended good hygiene and manufacturing practices applies to the manufacture of steel for packaging intended to come into contact with foodstuffs	http://www.google.be/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0CCcQFjAB&url=http%3A%2F%2Fwww.vet.agri.ee%2Fstatic%2Ffiles%2F705.1.GM%26HP_Final_2009.pdf&ei=oOr-VMbDKKqd7Abo7YGgDw&usg=AFQjCNHFywLGaM76w09YSk2qELPaZ-oE0A&bvm=bv.87611401,d.ZGU	design process	material selection	

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
CETS (2002), Reference document on best available techniques for the surface treatment of plastic and metals using electrolytic or chemical process	see BREF STM		finishing processes - surface treatment		BREF STM
CETS (2001), Reference Document on best available techniques Surface Treatment of metals and plastic materials using electrolytic or chemical process (volume of treatment vats > 30 m^3)	see BREF STM		finishing processes - surface treatment		BREF STM
Nordic-Council (2002), DEA- an aid for identification of BAT in the inorganic surface treatment industry & Environmentally acceptable	The report describes the latest technical developments and presents the results of a new benchmarking method to identify BAT and the possibilities of		finishing processes - surface treatment		BREF STM and BREF STS

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
metalworking processes	reducing environmental impacts from surface treatment				
BAT and Cleaner technology in environmental permits - part 2: surface treatment (2009)	The overall aim of the project is to ensure that the Nordic industry is producing according to technologies and methods that lead to the lowest possible impact on the environment. This overall aim should be achieved through formulation of conditions in environmental permits and licenses which are as uniform as possible1 within the various industrial sectors. The immediate aim is to elaborate an easy-to-use tool for Nordic environmental authorities providing	http://www.google.be/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=8&cad=rja&uact=8&ved=0CEQQFjAH&url=http%3A%2F%2Fnorden.diva-portal.org%2Fsmash%2Fget%2Fdiva2%3A700592%2FFULLTEXT01.pdf&ei=aEDvVIeYAoXWapK5gqgO&usg=AFQjCNE6Gp_aZ2ZAlYy_pjf19WVamxc4pg	finishing processes - surface treatment		BREF STM and BREF STS

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
	them with guidance, and to get an overview of practices used by Nordic colleagues and an overview of the Nordic experience concerning terms, BAT and CT.				
UNEP; MAP and RAC/CP (2002), Alternatives for preventing pollution in the surface treatment industry	The objective of this study is to present the options for pollution prevention at source which could be implemented in Mediterranean industries of this sector within the various processing stages (washing, degreasing, pickling, metallic coating, etc.)	http://www.unepmap.org/index.php?s_sort=title&module=library&mode=pub&action=results&s_category=&s_keywords=&s_title=&s_year=&page=&s_descriptors=Surface+treatment+industry&s_author=&s_type=&s_final=&s_mnumber=	finishing processes - surface treatment		BREF STM and BREF STS

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
pollution prevention in the metal machining industry (2005)	The principal objective of this manual is to inform enterprises working in the metal machining sector of the opportunities available to them for integrated pollution prevention. In this way they can foresee, and minimize, the environmental impact of their activity, while at the same time they can be encouraged to look into new ways of preventing pollution in their factories. This manual is divided into six sections: Introduction, Processes, Environmental Aspects, Pollution prevention and reduction opportunities, Practical case studies and Conclusions.	http://www.cprac.org/en/media/studies/sector-studies?page=1	forming processes (e.g. bending); finishing processes - heat treatment		BREF FMP

reference	*short description of the field of application*	*source*	*link with Fabricated Metal Products activities (see §1.3)*	*link with environmental issues*	*covered by*
Pollution Prevention for the Electroplating and Metal Finishing Industry (Kansas Small Business Environmental Assistance Program)	The document covers pollution prevention strategies that can be implemented to minimize the generation and release of wastes. The manual introduces pollution prevention concepts applied to common processes, gives an overview of some of the alternative technologies available to minimize pollution, and briefly discusses regulatory requirements in the state of Kansas. Case studies and success stories from shops using these technologies are included to show how others have reduced their waste streams and their regulatory requirements	Metal Finishing & Pollution Prevention	finishing processes - surface treatment	waste (hazardous)	BREF STM

1.6. Scope of the proposed best environmental management practice in the Fabricated Metal Product manufacturing sector

BEMPs aim at improving the environmental performance of companies, taking into account the relevant direct and indirect environmental impacts of the production processes and of the entire value chain of the Fabricated Metal Product manufacturing sector. To reach a high level of effectiveness, the BEMPs must be selected focusing on the areas of the value chain having a high environmental pressure. To ensure policy coherence, the BEMPs must be complementary to the existing EU legislation, policy instruments and best practice guidance.

Therefore the analysis of the data in the previous paragraphs on economics (§1.2), environmental aspects and pressures (§1.3) and on EU legislation, policy instruments and best practice guidance (§1.5) have to be combined in order to identify the scope of this study.

Environmental impact

There is no specific EU legislation or policy instruments which stimulates or obligates the sector directly to change or reduce their **material uses**. However, the use of materials is one of the main environmental aspects of the whole Fabricated Metal Products sector.
The main impact is located upstream, in the production of ferrous and non-ferrous metals. In the Fabricated Metal Products sector, the removing processes cause the highest impact on the use of materials. In the downstream activities, also high amounts of material are used (e.g. metal structures in building materials).
The direct emissions of the upstream value chain are covered by the BREF NFM and BREF FMP. But by focusing on concurrent engineering in the Fabricated Metal Products sector, the material use upstream will reduce.

The Fabricated Metal Products sector is an **energy** intensive sector, where the utilities in the supporting processes are responsible for the high energy use. The Energy efficiency directive (2012/27/EU) and the BREF ENE give companies an incentive to reduce the use of primary energy. For the other energy intensive process steps, like forming, removing and additive process, there are no specific policy instruments to trigger the companies to reduce their energy use. The energy uses in the upstream processes and in the finishing processes are covered by the BREFs NFM, BREF FMP, BREF STS and BREF STM.

In general, the sector is less impactful in terms of **water use**. Only the finishing processes are important consumers of water, and these aspects are covered by the BREF STS and STM.

In the Fabricated Metal Products sector different auxiliary materials are used in the production process. The removing, joining and finishing processes are characterized by the highest use of **consumables**. In case of chemicals, the environmental aspects

of these products are regulated by REACH. For other types of auxiliary materials, there are no specific legislation or policy instruments for the Fabricated Metal Products sector.

As resource use is important for the sector, the BEMPs will focus on this topic. Priority will be given to practices in the Fabricated Metal Products sector, with a positive effect on the upstream and downstream value chain and to the forming, removing, additive and joining processes in the sector. Less attention will be given to the utilities and finishing processes, since there are already documents (BREFs), legislation and policy instruments to control this impact.

Emissions
The finishing processes cause the highest direct emissions in the Fabricated Metal Products sector, especially to **water**. The latter cause a negative impact on the internal waste water treatment plants. The emissions of these activities are regulated in the IED (2010/75/EC), and are subject of the BREF STS and BREF STM.
Other emissions (**to air, odour, noise and vibrations**) can be found in the joining, forming and removing processes. For each of these emissions, there is general legislation (2001/379/EC; 2001/81/EC; 2003/87/EC and 2000/14/EC(3)) to control or regulate the impact. But none of these is specific for the sector.

With exception of the finishing processes, which are covered by the BREF, all manufacturing processes of the Fabricated Metal Products sector are subject for BEMPs to reduce the impact.
The indirect emissions caused upstream in the value chain, can only be influenced by the Fabricated Metal Products sector when the sector itself uses less materials. This will be studied under the BEMPs for resource use.

Waste
Most of the waste in the sector is generated in the removing processes. The waste produced is **non-hazardous waste** and must be seen as left overs of materials. The solutions of these problems are linked with the success of a better material use.
The finishing processes are the main source of **hazardous waste and liquid waste**. These processes are subject to legislation (IED, 850/2004) and the BREFs STS and STM.

Subsectors in the Fabricated Metal Products sector

Based on Table 7, which describes the direct and total emissions and resource use of the Fabricated Metal Products subsectors, as well as Figure 5, which gives a view on the relative share of turnover for the different subsectors, and based on the expert judgment of the consortium, we conclude that:

- The types of processes applied do not significantly differ depending on the subsectors. Similar processes and activities are used in the entire Fabricated Metal Products sector, like logistics, utilities and manufacturing processes (e.g. removing forming, additive processes). There are no clear indications of

important differences between the subsectors in terms of processes and activities;

- There is a direct link between the economic importance of a subsector (the turnover) and almost all studied direct emission and resource use. NACE 25.1 (manufacture of structural metal products) followed by NACE 25.9 (manufacture of other fabricated metal products) and NACE 25.6 (treatment and coating of metals and machining) are the economically and environmentally most important subsectors;
- Only the direct emissions (and consequently linked the total emissions) of NMVOC do not follow this logic. NACE 25.1, emits half of the NMVOC of the NACE 25.9 while both are economically similar. One can say that the NACE 25.1 subsector controls its emissions of NMVOC better than other subsectors.

In general, however, we conclude that the processes, the emissions and resource use are comparable in all subsectors. Therefore, the BEMPs will be defined on the level of the entire NACE 25 sector. As explained under §1.1 (Composition of the Fabricated Metal Products sector) the manufacturing and supporting activities of the NACE 25 sector are also common used within other sectors. By defining the BEMPs we will focus on these activities, rather than on the entire NACE division 25.

Scope at activity level

- Supporting processes:
  - Management, procurement, supply chain management, quality control;
  - Utilities and maintenance.
- Manufacturing processes (red border line in Figure 9 and Figure 10):
  - Forming processes;
  - Removing processes;
  - Additive processes;
  - Joining processes;
  - Finishing processes.
- Scope on organizational level (red border line in Figure 6):
  - Product design;
  - Concurrent engineering.

Logistics, handling and storage will be out of the scope since these activities are comparable with all production industries that make semimanufactured or end products.

Emission treatment is out of the scope. By defining the BEMPs we give priority to reduce the environmental impact and improving the environmental performance by using the first steps of the sustainability principles of as defined under the Trias energetica (Box 2), the Lansink's ladder (Box 3) and under the IED (Box 4).Emission control is always the last step along these principles.

Following the principles of the circular economy, there is no waste / emission, because the by-products become raw materials for new products (Box 5).

Box 2. Trias energetica

Trias energetica was defined by the University of Delft for the built environment. The concept helps to achieve energy savings, reduce our dependence on fossil fuels, and save the environment.

The 3 elements of Trias Energetica are:

1. Reduce the demand for energy by avoiding waste and implementing energy-saving measures;

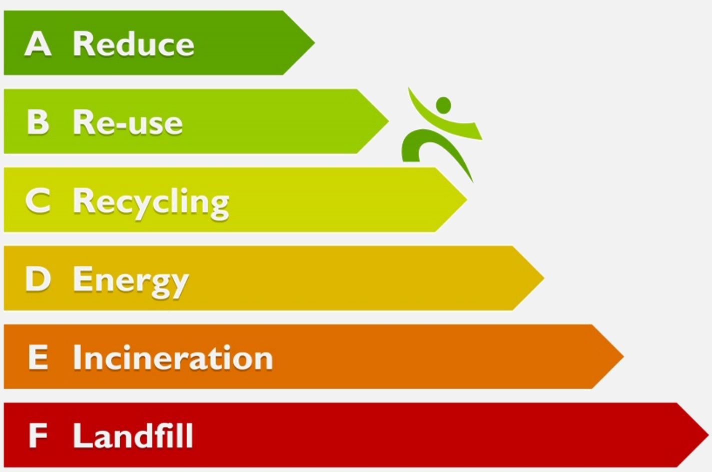
2. Use sustainable sources of energy like wind, the sun, water and the ground;

3. Use fossil fuel energy as efficiently as possible and only if sustainable sources of energy are unavailable.

In addition, try to compensate the damage you do to the environment by compensating your pollution by doing good things like planting trees.

Box 3. Lansink's ladder

The Lansink's ladder is an order of preference on how to manage waste. It was conceived in 1979 by the Dutch politician Ad Lansink and consists of the following steps:



Box 4. Principles of Article 11 of the IED (General principles governing the basic obligations of the operator)

Member States shall take the necessary measures to provide that installations are operated in accordance with the following principles:

(a) all the appropriate preventive measures are taken against pollution;

(b) the best available techniques are applied;

(c) no significant pollution is caused;

(d) the generation of waste is prevented in accordance with Directive 2008/98/EC;

(e) where waste is generated, it is, in order of priority and in accordance with Directive 2008/98/EC, prepared for re-use, recycled, recovered or, where that is technically and economically impossible, it is disposed of while avoiding or reducing any impact on the environment;

(f) energy is used efficiently;

(g) the necessary measures are taken to prevent accidents and limit their consequences;

(h) the necessary measures are taken upon definitive cessation of activities to avoid any risk of pollution and return the site of operation to the satisfactory state defined in accordance with Article 22.

in general one can split up the actions in three main stages:

- Prevention of emissions;
- Reduction of emissions;
- Control of emissions.

Box 5. The circular economy principle (Ellen MacArthur foundation, 2013; EU, 2014)

1. Circular economy is a global economic model that decouples economic growth and development from the consumption of finite resources;
2. Distinguishes between and separates technical and biological materials, keeping them at their highest value at all times;
3. Focuses on effective design and use of materials to optimize their flow and maintain or increase technical and natural resource stocks;
4. Provides new opportunities for innovation across fields such as product design, service and business models, food, farming, biological feedstocks and products;
5. Establishes a framework and building blocks for a resilient system able to work in the longer term.

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CHAPTER 2. Best environmental management practice

2.1. Technique portfolio

The list of proposed BEMPs for the Fabricated Metal Products sector are a range of possibilities for companies to improve their environmental performance. Some of the BEMPs will reduce the raw and auxiliary material or energy use in the Fabricated Metal Products sector, while others will have a main impact upstream or downstream (direct versus indirect effects). In most of the cases, there is an impact on different environmental aspects in different places in the value chain.

The following two tables (Table 14 and Table 15) present how the most relevant environmental aspects and the related main environmental pressures are addressed, either in this document or in other the Best Available Techniques Reference Documents[28]. For the aspects covered in this document, the tables mention the best environmental management practices (BEMPs) to address these.

[28] Other relevant sources of information are listed in paragraph 1.5. These include EU legislation, policy instruments and best practice guidance.

Table 14. Most relevant direct environmental aspects for the Fabricated Metal Products companies how these are addressed

Most relevant direct environmental aspects	*Related main environmental pressures*	*BREF*	*BEMPs*
Supporting processes			
Management, procurement, supply chain management, quality control	Raw materials use Energy use Consumables use Water use		2.2.1 Extend the lean principles with measures for energy and material consumption 2.2.2 Measures for stock reduction - while keeping customer demand flexibility 2.2.3 Cross-sectoral and value chain collaboration (by communication and integration) 2.2.4 Chemical leasing & Chemical management services 2.4.2 Co-design and open innovation with downstream partners to reduce environmental impact during product life cycle
Utilities and maintenance	Energy use Water use Consumables use Emissions to water Odour Other emissions (noise, vibration)	STM STS ENE ICS	2.2.5 Energy management 2.2.6 Efficient ventilation 2.2.7 Optimal lighting 2.2.8 Energy and water savings of cooling circuits 2.2.9 Efficient use of compressed air systems 2.2.10 Reduction of standby energy of metal working machines 2.3.3 Selection of coolant as environmental and performance criterion 2.3.9 Reduce the energy for paint booth HVAC with predictive control 2.3.10 Selection and optimization of thermal processes for curing wet-chemical coatings on metal products
Manufacturing processes			
Forming processes	Raw materials use		2.2.1 Extend the lean principles with measures for energy and material

Most relevant direct environmental aspects	*Related main environmental pressures*	*BREF*	*BEMPs*
	Energy use Other emissions (noise, vibration) Non-hazardous waste		consumption 2.2.6 Efficient ventilation 2.2.8 Energy and water savings of cooling circuits 2.2.10 Reduction of standby energy of metal working machines 2.3.1 Application of solid low-friction coatings on tools and components 2.3.2 Application of wear- and corrosion-resistant coatings of tools and equipment 2.3.3 Selection of coolant as environmental and performance criterion 2.3.4 Incremental Sheet metal Forming (ISF) as alternative for mould making 2.3.5 Additive manufacturing of complex equipment - flow optimization for optimal heat transfer and temperature control 2.3.6 Multi-directional forging: a resource efficient metal forming alternative 2.3.7 Hybrid machining as a method to reduce energy consumption
Removing processes	Raw materials use Energy use Consumables use Water use Emissions to water, air, odour Non-hazardous waste Liquid waste		2.2.1 Extend the lean principles with measures for energy and material consumption 2.2.6 Efficient ventilation 2.2.8 Energy and water savings of cooling circuits 2.2.10 Reduction of standby energy of metal working machines 2.3.1 Application of solid low-friction coatings on tools and components 2.3.2 Application of wear- and corrosion-resistant coatings of tools and equipment 2.3.3 Selection of coolant as environmental and performance criterion 2.3.7 Hybrid machining as a method to reduce energy consumption 2.3.8 Machining of near-net-shape feedstock

Most relevant direct environmental aspects	*Related main environmental pressures*	*BREF*	*BEMPs*
Additive processes	Raw materials use Energy use Other emissions (noise, vibration) Non-hazardous waste		2.2.1 Extend the lean principles with measures for energy and material consumption 2.2.6 Efficient ventilation 2.2.8 Energy and water savings of cooling circuits 2.2.10 Reduction of standby energy of metal working machines 2.3.3 Selection of coolant as environmental and performance criterion 2.3.5 Additive manufacturing of complex equipment - flow optimization for optimal heat transfer and temperature control 2.3.7 Hybrid machining as a method to reduce energy consumption 2.3.8 Machining of near-net-shape feedstock
Joining processes	Energy use Consumables use Raw materials use Emissions to air, odour Other emissions (noise, vibration) Non-hazardous waste		2.2.1 Extend the lean principles with measures for energy and material consumption 2.2.4 Chemical leasing & Chemical management services 2.2.6 Efficient ventilation 2.2.8 Energy and water savings of cooling circuits 2.2.10 Reduction of standby energy of metal working machines 2.3.3 Selection of coolant as environmental and performance criterion 2.3.7 Hybrid machining as a method to reduce energy consumption
Finishing processes	Water use Energy use Consumables use Raw materials use Emissions to water, air, odour Hazardous, non-hazardous and	STM STS	2.2.1 Extend the lean principles with measures for energy and material consumption 2.2.4 Chemical leasing & Chemical management services 2.2.6 Efficient ventilation 2.2.8 Energy and water savings of cooling circuits 2.2.10 Reduction of standby energy of metal working machines

Most relevant direct environmental aspects	*Related main environmental pressures*	*BREF*	*BEMPs*
	liquid waste		2.3.1 Application of solid low-friction coatings on tools and components 2.3.2 Application of wear- and corrosion-resistant coatings of tools and equipment 2.3.3 Selection of coolant as environmental and performance criterion 2.3.7 Hybrid machining as a method to reduce energy consumption 2.3.9 Reduce the energy for paint booth HVAC with predictive control 2.3.10 Selection and optimization of thermal processes for curing wet-chemical coatings on metal products

Table 15. Most relevant indirect environmental aspects for the Fabricated Metal Products companies how these are addressed

Most relevant direct environmental aspects	*Related main environmental pressures*	*BREF*	*BEMPs*
Upstream - Design process			
Raw material production Product equipment	Raw materials use Energy use Consumables use Water use Emissions to water, air Other emissions (noise, vibration) Hazardous, non-hazardous and liquid waste	FMP NFM SF ENE LCP	2.2.3 Cross-sectoral and value chain collaboration (by communication and integration) 2.2.4 Chemical leasing & Chemical management services 2.4.1 Remanufacturing of high value components
Downstream - Manufacturing processes			
Assembly Product finishing	Raw materials use Energy use	WT WI	2.2.3 Cross-sectoral and value chain collaboration (by communication and integration)

Most relevant direct environmental aspects	*Related main environmental pressures*	*BREF*	*BEMPs*
production and packaging logistics	Noise Non-hazardous waste		2.4.2 Co-design and open innovation with downstream partners to reduce environmental impact during product life cycle 2.4.1 Remanufacturing of high value components
Value chain – Design process			
Material selection	Raw materials use Energy use Consumables use Water use Non-hazardous		2.2.3 Cross-sectoral and value chain collaboration (by communication and integration) 2.4.2 Co-design and open innovation with downstream partners to reduce environmental impact during product life cycle 2.3.1 Application of solid low-friction coatings on tools and components 2.3.2 Application of wear- and corrosion-resistant coatings of tools and equipment 2.3.5 Additive manufacturing of complex equipment - flow optimization for optimal heat transfer and temperature control
Value chain – market processes			
Use Phase Refurbishment Disassembly Material recycling	Other emissions (noise, vibration) Hazardous, non-hazardous waste		2.2.3 Cross-sectoral and value chain collaboration (by communication and integration) 2.4.2 Co-design and open innovation with downstream partners to reduce environmental impact during product life cycle 2.4.1 Remanufacturing of high value components

2.2. Best environmental management practices for the supporting processes

The proposed BEMPs for supporting processes are split up in BEMPs for Management, procurement and supply chain management:

- 2.2.1 Extend the lean principles with measures for energy and material consumption
- 2.2.2 Measures for stock reduction - while keeping customer demand flexibility
- 2.2.3 Cross-sectoral and value chain collaboration (by communication and integration);
- 2.2.4 Chemical leasing & Chemical management services;

and BEMPs to optimize the utilities:

- 2.2.5 Energy management;
- 2.2.6 Efficient ventilation;
- 2.2.7 Optimal lighting;
- 2.2.8 Energy and water savings of cooling circuits;
- 2.2.9 Efficient use of compressed air systems
- 2.2.10 Reduction of standby energy of metal working machines

2.2.1. Extend the lean principles with measures for energy and material consumption

Description

Lean principles can be applied in companies in the Fabricated Metal Product manufacturing sector to review and improve their production processes. The lean principles are used to detect inefficiencies or waste. These types of waste 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.

Important for companies in the sector is that all seven wastes cause energy and possibly materials losses. However, this is something often overlooked and the savings related to the implementation of lean principles are not properly quantified. Studies suggest that energy use could be reduced in manufacturing and industrial sectors by 75% with the currently available technologies at little cost (Miller, 2009). Overproduction leads to the consumption of energy by operating equipment to make products which are not needed. This is related to the other types of wastes being created, such as inventory which needs to be heated, cooled, conveyed and lighted using all significant amounts of energy. Transportation of products uses more energy. Waiting itself may not be the main category of waste, however, the light, heat and running equipment consumes energy while people/staff are waiting. Defects during production process use significant amounts of energy. All of the energy to manufacture the products is wasted in case of defects since the products need to be made again, and often people spend time correcting, reporting and analysing the defect which uses energy in a variety of ways. Processing waste streams creates energy losses when the equipment size and speed are inappropriate to get the job done efficiently. Motion waste is the most challenging category to link with energy waste because it relates to human motion. Excessive human motion can cause unsafe work conditions, lower productivity or poor quality which has consequences on energy efficiency.

These seven types of waste can be extended with two more types, relevant for the Fabricated Metal Products sector: system integration/optimization and technological improvements. Example for system integration and optimization are reuse of waste heat between different processes, cascading waste water etc. The technological improvements can highly impact investment decision especially if Total Cost of Ownership (TCO) is a key criterion e.g. high efficiency pumps (evaluation of new pomp motor versus frequency converters on old pump motors. These types of waste are related to the application of specific systems or technologies. The waste of some

technologies, e.g. produced heat, is often not efficiently applied in other technologies or systems within company (see Figure 11).

	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

Figure 11. Lean waste concept can be translated into energy terms and is strengthened by two additional levers (http://www.mckinsey.com)

In order to implement lean principles in a company from the sector, the following five-step process has to be taken into account (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 want the next step for a company is to identify how it can delivering (or not) that to them.
3. Create flow by eliminating waste: Typically when 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 on the service and then creating the process to respond to this. Such that a company produces only what the customer wants when the customer wants it.
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.

Figure 12. Five-step process for implementing lean principles in a company (Lean Enterprise Institute, 2015)

A lot of the other BEMPs illustrated how the lean principles can be introduced in the utilities and production steps.

Achieved environmental benefits

Effectively implementing lean principles in a company can lead to various environmental benefits, all related to the specific production process. In the case of the Fabricated Metal Products sector, the main environmental benefits is a reduction of resource use, i.e. energy (and CO_2-emissions) and materials. Significant reductions of the waste streams and the amount of waste produced during manufacturing are known as well.

Appropriate environmental indicators

Indicators for measuring performance of companies using the lean principles depend on the production processes and materials, but in general this indicators give an overall view on how companies are doing:

- kg raw material used per produced unit;
- total energy use per produced unit;
- kg waste produced per year or per product;
- % of the products which complain to the quality standards.

More specific, the indicators can give information on:

- Overproduction & waiting: Measure the energy needed to manufacture one product kWh/product shipped. The energy use is in this case to be measured for an entire production entity and over a fixed period of time;
- Transportation - Motion: Internal and external transport. Allocate the energy use (e.g. gas, electric power of forklift truck) to sold production volumes. (kWh/products shipped);
- Over specification: This can be over specification of process equipment like compressed air (oil free, pressure, flow, etc.) which might be reduced without

compromising the quality. Over specification of the manufactured product or packaging can also lead to unrequired process steps. Finally also improved process control can often eliminate the need product testing. Defining test/inspection sample size in function of the number and type of detected defects. Over specification can be tackled by qualitative measures like: Testing and define the specification per process or operation.

- Inventory: If the indirect impact of inventory (Energy use for lighting, heating, etc.) can be measured this can be used as an indicator e.g. kWh/products sold, kWh/products made. (See also BEMP 2.2.2 on Measures for stock reduction - while keeping customer demand flexibility);
- Rework/Scrap: Often the weight can be easily measured. (kg scrap per number of products). To associated lost energy is hard to allocate;
- Employee potential: Number of actions coming from shop floor employees (suggested, reviewed and implemented);
- System: Here typical input output evaluations are set up. kWh heat used in processes/ kWh heat dissipated through cooling. Water (rainwater, drink water,…) used versus waste water treated or emitted;
- Technology: Having a technology watch for the processes with the highest impact (energy use, material use, emission, etc.) makes it possible to review the current processes with the best available technologies on a regular basis.

Cross-media effects

In order to optimally incorporate continuous improvement and strive for reductions in resource use and waste production in a company, a mature lean manufacturing system is required. Applying the lean principles and five-step process without an overall lean management approach might lead to a suboptimal outcome and even additional costs.

Operational data

Case study Toyota (Japan) – Tsutsumi plant, (Miller, 2009)

The lean principles were implemented in order to save energy and reduce waste as well as to enhance eco-thinking and renewable energy systems. These measures have contributed to Tsutsumi's overall CO_2 emissions being cut by more than 50%since 1990 (ca. 150,000 tonnes). Furthermore, since Prius production began in 1997, the plant has reduced the amount of waste going to landfill by 82% and has instituted plans to achieve complete elimination of incinerated waste. Within Lean production environments Value Stream Mapping/Method (VSM) is a used to identify the potential of process improvements.

Fraunhofer proposed and implemented the principles of the Value Stream Method (VSM) to analyse the energy use per process. It allows the companies familiar with the well-proven VSM methodology to analyse the energy efficiency. Figure 13 gives an overview of these principles

Figure 13. Principles of the Value Stream Method (Franhofer, 2011)

The result of this analysis is a systemic procedure in three steps for (Figure 15):

1. Holistic collection and evaluation of energy consumption in production processes;
2. Increasing energy efficiency by using design guidelines;
3. Finally optimization of energy consumption;

Typical approach in line with value stream mapping can be:

1) Identification and scope the process to investigate;

2) Identification of energy consumption in the productions (leaks compressed air, power consumption equipment, data acquisition to enable the evaluation of the current state (power measurements, pick up voltages, etc.). Relate the power consumption to the process steps (e.g. power-time graphs);

3) Set up a value stream method based on 'Energy intensity'. This is the production process-related energy consumption for one product;

4) Perform analysis and define action steps for the most energy intensive process steps. The two fundamental questions to find opportunities are:
    a. Is this energy end use needed? (Does this energy really bring customer value?);
    b. Is there a way to deliver this end use more efficiently in supporting process? (What alternatives exist to provide the needed customer value?).

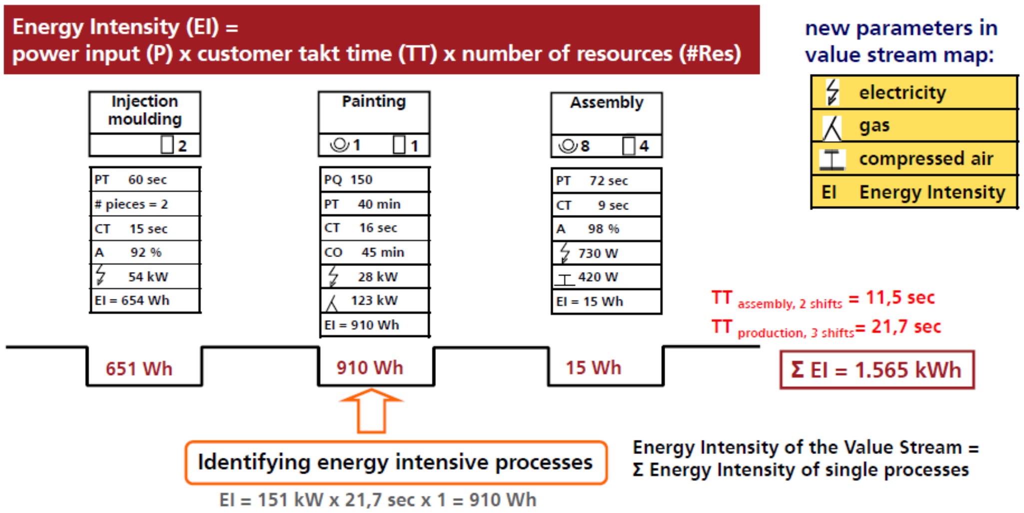

Figure 14: Energy Value Stream Analysis is similar representation as classic VSM visualisation (Fraunhofer, 2011)

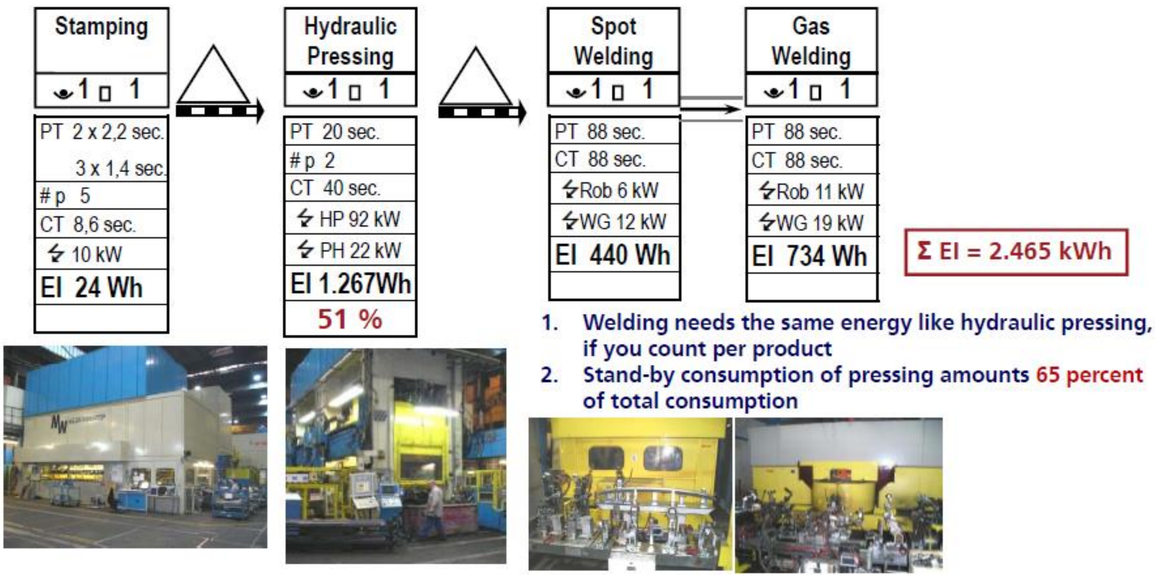

Figure 15. Production of a front bumper made of 5 parts in 4 production steps – calculation of energy intensity demonstrates effect of product related approach (Fraunhofer, 2011)

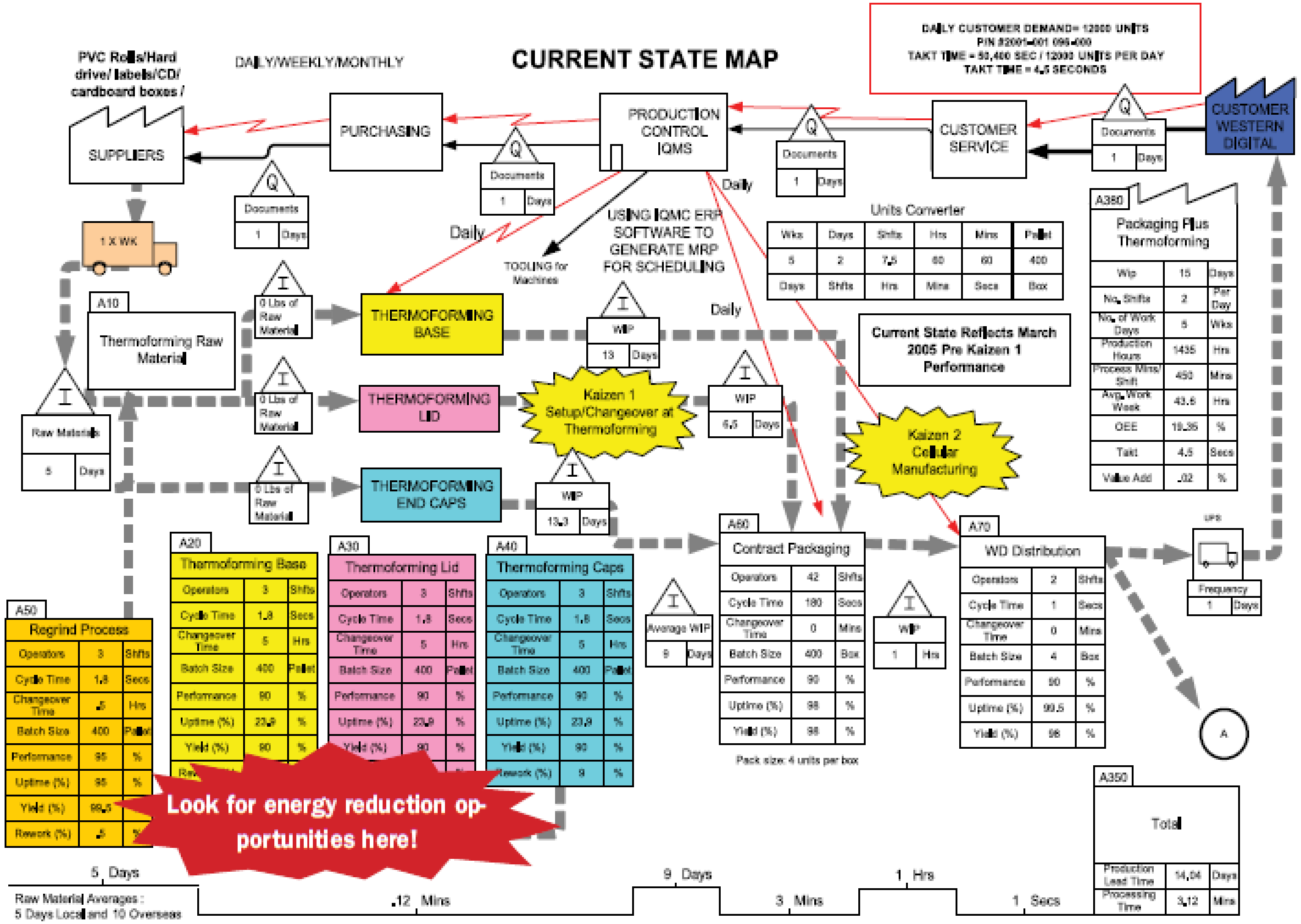

Figure 16. Example Value Stream Map shows a value stream map from a value and energy stream (EPA, 2011)

Applicability

The lean principles can be implemented in companies of all level of maturity. These principles can easily be translated into effective actions applicable for quick-wins in a company ("low hanging fruit") as well as more complex opportunities.

Economics

Lean manufacturing is proven and widely used in many companies and sectors. It proved to be effective in reducing waste (7 types) and therefore, in more efficiently expenditure of resources, e.g. lower energy, materials and operational costs.

Driving force for implementation

The main driving force for implementation is a combination of productivity increase with a reduction of energy and material use.

Reference organizations

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2.2.2. Measures for stock reduction - while keeping customer demand flexibility

Description

Companies in the Fabricated Metal Products sector often have an extensive stock of materials and goods in order to cope with flexible customer demand. The stock contains raw materials, work in progress (WIP), purchased parts and components, semi-finished product, finished products, spare parts, etc. All these materials and goods requires space, not only in the storage area, but also on the shop floor.
Quick Response Manufacturing (QRM) is a recent, new production approach which drastically reduces the lead time and results in a lower stock. If products can be made in a few days instead of a few weeks, then, at a certain moment, less materials need to be stored in the company. QRM will reduce the stock directly, proportional to the lead time (Little's Law).

Shorter lead times 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.
QRM applies cellular production layouts (Figure 18) that typically require less floor space for equal levels of production compared to functional layouts (Figure 17 and Figure 18). The reduction in required floor space will also lead to a reduction of energy use for heating, cooling and lighting. It can also lead to a reduction of consumption of resources and generation of waste, e.g., fluorescent bulbs and cleaning supplies. 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 wastes, can be reduced.

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

- *Functional to Cellular*: Functional departments must be replaced by QRM. QRM cells become the main organizational unit. QRM cells are more flexible and holistic in their implementation compared to other cell 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;
- *Specialized Workers to a Cross-trained Workforce*: Workers need to be trained to perform multiple tasks.

Efficiency/Utilization Goals to Lead Time Reduction: To support this new structure, companies must replace cost-based goals of efficiency and utilization with the overarching goal of lead time reduction.

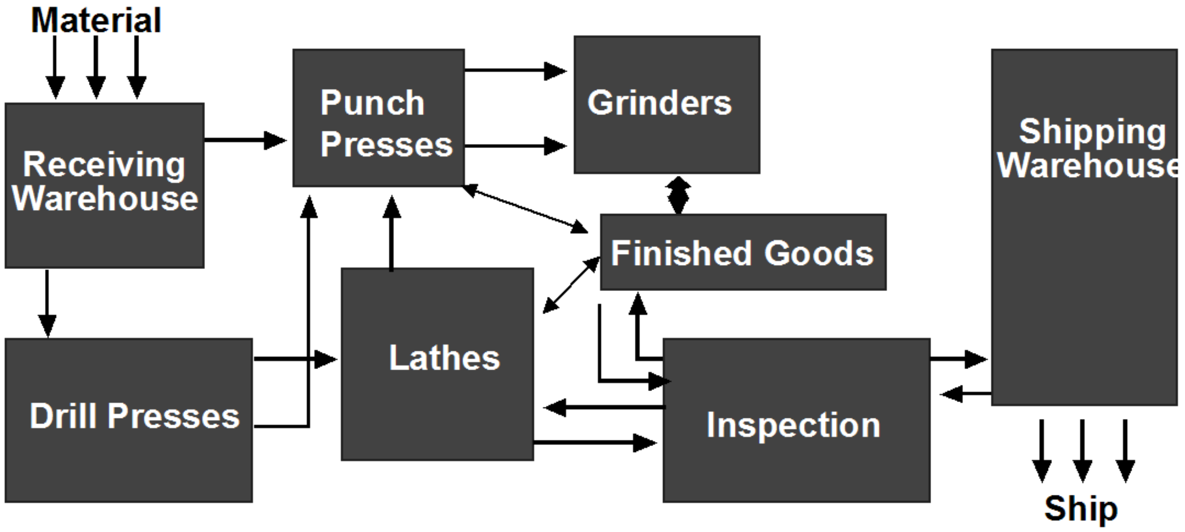

Figure 17. Scheme of a traditional organization of the shop floor (Teim, 2010)

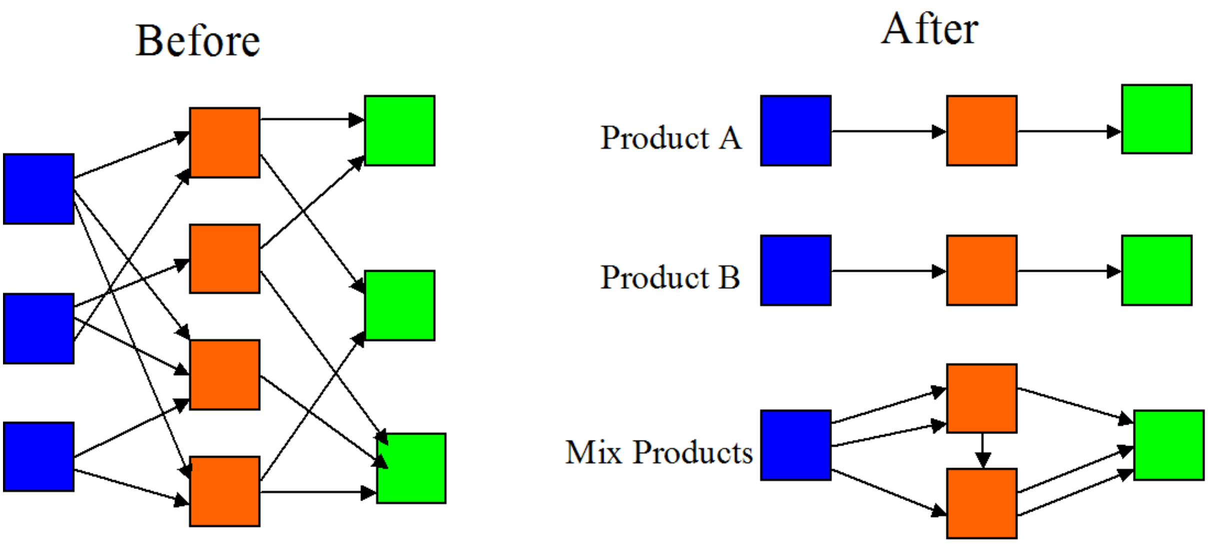

Figure 18. Organization of the shop floor: before: traditional functional layout; after: cellular layout (Teim, 2010)

The main building block of the QRM organization is the QRM cell. Extending the concept of cellular manufacturing, QRM cells are designed around a Focused Target Market Segment (FTMS) – a segment of the market in which shorter product lead times provide the company with maximum benefits. Resources in a cell are dedicated (only to be used for jobs in the cell), collocated (located in close proximity to each other) and multifunctional (cover different functions). QRM cells complete a sequence of operations ensuring that jobs leave the cell completed and do not need to return.

The work organization in QRM cells is based on team ownership. Provided with a job and a completion deadline, teams can decide independently on how to complete the job. To ensure quick response to high-variety demand, workers in QRM cells need to go through

cross training. Creating spare capacity and defining optimal batch size are key elements of this strategy.

Many cost-based organizations aim for machines and labour to be utilized at close to 100% of capacity. QRM criticizes this approach as counterproductive to lead time reduction based on queuing theory, which shows that high utilization increases waiting times for products and increasing inventory. In order to be able to handle high variability in demand and products, QRM advises companies to operate at 80% capacity on critical resources.

Common efficiency measures encourage production of parts in large batch sizes. From the QRM perspective, large batch sizes lead to long waiting times, high WIP and inventory, and ultimately long lead times. Long lead times in turn result in multiple forms of waste and increased cost as described above. Thus, QRM encourages enterprise to strive towards batch sizes that minimize lead times.

This approach requires involvement of the company executive management since it requires an integrated approach over different company departments like sales, materials management (supply chain), production organization, product design etc. Product design, sales, operations and planning that are driven by lead time (time driven production) create supporting auto-replenishment systems, cellular manufacturing allowing fast reaction in ramping up and ramping down and in implementation of product improvements.

Based on information of the Centre for Quick Response Manufacturing (2015) and QRM Centre Europe (2015).

Achieved environmental benefits

Reducing defects due to faster detection has several environmental benefits:

- fewer defects decreases the number of products that must be scrapped;
- fewer defects also means that the raw materials, energy, and resulting waste associated with the scrap are eliminated;
- fewer defects decreases the amount of energy, raw material, and wastes that are used or generated to fix defective products that can be re-worked.

Shifting to rightsized equipment means that production equipment is sized to work best for the specific product mix being produced, as opposed to the equipment that would meet the largest possible projected production volume. Rightsized equipment is typically less material and energy-intensive (per unit of production) than conventional, large-scale equipment.

Less floor space for equal levels of production can reduce energy use for heating, air conditioning and lighting if additional production can be realized within the same building (European business, 2015). In other words more output is generated out of the same resources (building and infrastructure) and with less energy, which reduces the environmental impact

Appropriate environmental indicators

Since stock is directly proportional with lead time (Little's Law), the lead time can be used as good indicator.

Additional indicators are:

- kg WIP per product range or Focused Target Market Segment (FTMS);
- kg products not meeting the quality requirements (none conforming products) per amount of product produced;
- m² floor space for storage.

Indicators expressing the overall energy efficiency, e.g. energy consumption per product produced (kWh per product range or FTMS).

Cross-media effects

Switching to cellular manufacturing systems, as a tool for stock reduction, can require investment in new equipment, and potentially the need to scrap the older (or refurbish and sell second hand), large-scale equipment geared more to batch-and-queue operations. This can initially produce scrap for recycling and/or waste.
Rightsizing and dispersing environmentally-sensitive production processes throughout a plant can disrupt conventional pollution control systems. For example, shifts 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, needs, and requirements. If environmental requirements are not addressed adequately during the conversion to cellular layouts and rightsized equipment, the organization can impact the environment adversely and/or fail to comply with applicable regulatory requirements.

Operational data

QRM theory recommends four common steps when implementing QRM:
QRM implementation requires company personnel to embrace the strategy's time-based principles. In a first step, a team of management and employees trained in QRM principles should compile a list of time wastes, creating awareness for the negative impact of long lead times on operations.

A cross-functional team starts studying the project, including a detailed analysis of the critical path, product volumes, strategic needs and other factors. This analysis leads to the definition of the Focused Target Market Segment (FTMS) for the QRM project. Using QRM principles, the planning team designs a QRM cell for the FTMS.

An implementation team consisting of the people in the new cell and members of the planning team can start training activities, cross-training of operators and – if needed – relocation of equipment to launch the cell. After cell launching, the implementation team continues support for the new cell and measures the critical path to monitor lead time changes.

Several cases published on QRM results illustrate improvements like (Centre for QRM, 2012):

- Lower stock (up to 60% reduction and up to 70% lower stock holding cost) and fewer late deliveries;
- Increased stock turns (up to 40%);
- Obsolescence reduction (over 30%).

Panimpex (BE) is a SME in the Fabricated Metal Products sector with main process activities: punching, bending, soldering, assembling. Panimpex reconsidered its production processes in order to reduce the lead times and inventory. Table 16 below gives an overview of the situation before and after the implementation of the stock reduction and QRM measures (Sirris, 2014):

Table 16. Panimpex results of QRM implementation (Sirris, 2014)

Before	*After*
Large change over time	Small effective change over times
Batch size: 50	Batch size: max. 10
Lay out: scattered work stations	Lay out: U- shaped cellular shape
Thru put time: 4 days per product	2 – 4 hours
Inventory: large inventory and large WIP quantities	Small inventory parts (almost no WIP)

Provan (BE) is a metal working company. Its main activities are sheet metal and steel pipe laser cutting, bending, forming, welding and assembling for a set of original equipment manufacturers (OEM) customers. Without 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. Due 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. With 50% less energy more revenue is created.

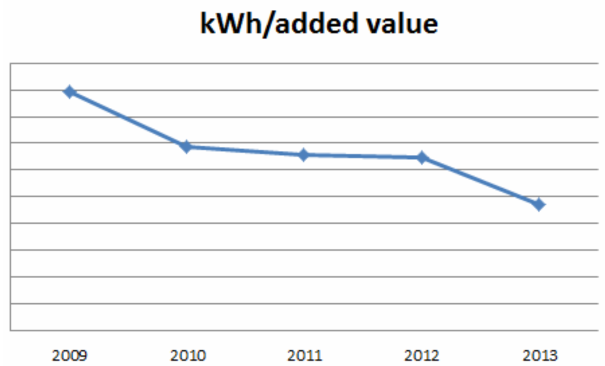

Figure 19. Evolution of the energy use (kWh) per added value after implementing a QRM at Provan (Sirris, Provan, 2015)

Applicability

Companies making products in low or varying volumes (not only in the Fabricated Metal Products sector) have used QRM as an alternative or to complement other strategies

such as Extend the lean principles with measures for energy and material consumption (§2.2.1).

The QRM principles can be applied in large scale as well as small scale organizations. The cellular approach and the single (small lot size) batches can be implemented in most Fabricated Metal Product manufacturing companies.

The supporting replenishment and control systems can be adjusted to the company's needs. Multiple supporting companies exist to guide companies towards QRM–implementation.

Economics

Unused or dead stock generates direct and indirect costs, including:

- *Opportunity Cost:* Dead inventory is money that is just sitting on shelves without producing any profit. It is an opportunity cost of investing the money in another business.
- *Direct losses:* Obsolete parts must be "scrapped", or sold under the price, which means a direct loss. Selling obsolete steel parts as scrap for example does not offset the cost of the raw materials and the indirect cost of manufacturing the parts.
- *Hidden costs.* Dead inventory incurs in costs such as insurance, rental space for storage, taxes, and time lost performing inventory recounts (Autologica, 2012).

Driving force for implementation

The main driving force for implementation is becoming (more) flexible and reactive to customers demand. This lead to:

- Reduction of total order to delivery time;
- Reduction of finished goods stock;
- Ability to respond to unexpected changes in demand without a degradation of service;
- Development of a cross-trained workforce for flexibility;
- Reduction last shot (last good piece) to first shot time (first good piece).

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2.2.3. Cross-sectoral and value chain collaboration (by communication and integration)

Description

In order to optimize processes and use of energy and resources at a more systemic level, collaboration of companies, cross-sectoral and throughout the value chain, is required. This is also the case for companies in the Fabricated Metal Products sector. Knowledge of the entire life cycle, value chain and networks relevant for the manufacturing processes are of utmost importance for further optimization of the processes.

This generic idea can be applied for the Fabricated Metal Products sector. Two major areas of collaboration are energy use and use of resources. In case of excesses of electricity or heat, an energy based collaboration can be set up. A waste stream generated in one company can be valuable resource for another company, and thus lead to a resource based collaboration.

Setting up cross sectoral collaborations can lead to industrial symbiosis. An industrial symbiosis is a local collaboration where public and private enterprises buy and sell residual products, resulting in mutual economic and environmental benefits. This means that two or more companies become interdependent of each other for their resource streams or energy streams. The largest industrial symbiosis network in Europe is situated in Kalundborg (Denmark). The Danish industrial symbiosis network consist of more than 15 companies from different sectors. However no companies from the Fabricated Metal Products sector are involved in the Kalundborg network. There is potential for cross sectoral collaboration, but on a smaller scale.

Companies in the sector need support to set up cross sectoral collaborations. Facilitating and targeted networking initiatives, focusing on matchmaking between companies (in and outside of the sector) help to overcome the barriers and improve the required knowledge and contacts. Matchmaking can be situated on several levels. Examples from the Fabricated Metal Products sector are linked to:

- Reuse of waste streams, including waste from metal product fabrication, e.g. cake, scrap, coating powder and solvents.
- closing the loop of valuable materials, e.g. special metal alloys.
- Linking materials' demand or equipment need with waste streams or standby, back-up or redundant equipment in other companies.

To match supply and demand additional research and pilot projects are needed.

However, anyone who has tried to catalyse business change, knows that this can and will never happen overnight. New practices are often taken on as pilot projects, prototypes or incremental tweaks, testing the water for a wider rollout if the numbers stack up and others are on board (Ellen Macarthur Foundation, 2015). This cross-sectoral and value chain collaboration is beneficial for both large and small companies. Identifying the appropriate collective platforms for matchmaking are a good starting point.

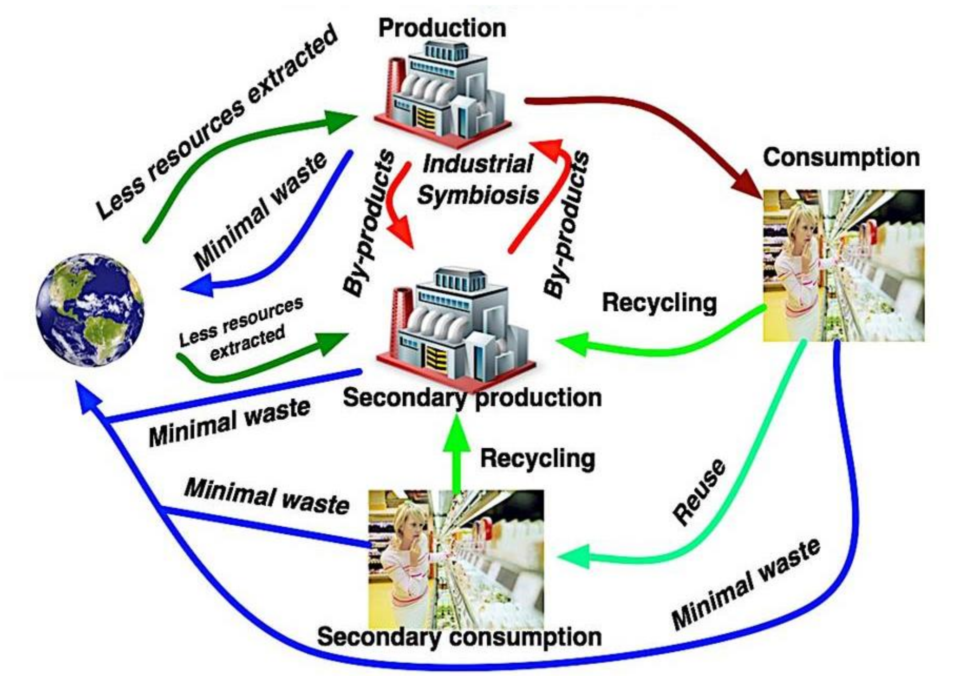

Figure 20. Representation of Industrial Ecology processes (GPEM, 2015)

To get started, the following steps can be used as guide:

- Identify the opportunity by mapping the energy or resource streams and their value/costs;
- Map all stakeholders in the process;
- Search for matchmaking 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 (stakeholders) to build up a more robust network.

Achieved environmental benefits

Cross-sectoral and value chain collaboration between companies will lead to a more optimal use of resources (e.g. materials, equipment, capacity, etc.) and energy and will lead to a more rational waste management. Due to this optimization significant reduction of CO_2 emissions can be achieved throughout the entire value chain. The collaboration initiatives, often starting from small scale experiments, enable open innovations and lower the barrier for future collaboration initiatives, which will eventually lead to a reduced environmental impact. Furthermore, due to the increased knowledge sharing via various platforms, knowledge building will be more efficiently.

Appropriate environmental indicators

Appropriate environmental indicators are:

- Participation in industrial symbiosis networks and exchange of material/energy etc. - Y/N;
- The amount of waste and sidestreams valorised outside the companies;

- Use of by-products or other energy sources from other industries within the industrial symbiosis network in various processes of Fabricated Metal Products industries:
  - scrap or other by-products – Y/N
  - steam – Y/N
  - renewable energy – Y/N

The CO_2 emissions in and outside the company, gives also a good indication, but to measure this, larger studies (e.g. Life Cycle Analysis) are needed to define the overall impact. Performing such a study and comparing the impact before and after (full) implementation provides better insights. In doing so, additional information on the main sources of impact is gathered whereas it is important to define precisely the borders of the carried out LCA study. To further control the process and make progress, focus on the life cycle phase with most impact might be a good indicator e.g. the functional unit of the carried out LCA study might be a meaningful and sound indicator. The Agfa case (see below) illustrates this. Since the production of aluminium is responsible for 80% of Agfa's climate change impact, the associated CO_2-emission in this life cycle phase is a good metric.

Cross-media effects

The overall environmental benefit might be compromised if only the economic interests are envisaged at the starting point (Marinos-Kouris and Mourtsiadis, 2013).
The environmental impact of cross sectoral collaborations is determined by reviewing the full material flows. This takes into account the benefits achieved, as well as the additional impact created. This to put the impact into perspective.
As an example, in the Agfa case the eco-impact associated to the use of raw materials is so high that the eco-impact of the recycling operations and reverse logistics are not significant.

The full life cycle needs to be examined to assure the *overall* environmental impact is reduced, and there is no shift from one life cycle phase to another.

Operational data

Some of the matchmaking initiatives are listed below.

Case study: Brainform (UK) – garment hanger re-use
Platforms, like Brainform, are looking for a maximum impact, they are not limited to the Fabricated Metal Products sector only: Brainform (UK), the global leader in garment hanger re-use, are seeing the far-reaching benefits of a circular business model by closing the materials loops of their products. The company belongs to both the Fabricated Metal Products 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.

This 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 21).

Figure 21. The Brainform re-use program (Brainform, 2015)

Even the best re-use systems require top-ups to keep the model working. Now, Brainform uses relationships with injection moulding production partners around the globe to manufacture the virgin hangers, rather than owning the factories and equipment themselves.

This shift has offered clear benefits for the company. Firstly, 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. The re-use model has also created jobs. This model is also less reactive to the fashion seasons, with the workforce remaining stable and consistent throughout the year, rather than creating unhelpful peaks and troughs. Brainform's re-use infrastructure also helps retail partners to save money on their waste removal as a value added service.

By moving from take-make-dispose to a closed loop of the materials, Brainform is demonstrating the multiple benefits that circular business models can bring: materials cost savings, greater resilience from price volatility, closer client relationships and new jobs (Brainform, 2015).

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

A study by the VOM (Belgium association for surface finishing techniques, Spooren, 2012) gives different possibilities for reuse and recycling of waste from the powder

coating process. For reuse as powder coating, the waste streams has 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).

Another 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 and small impurities (like grind, stones) are acceptable. Steelcase and GMI Composites 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 in the Fabricated Metal Products sector, provides ergonomic seating 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. The process is patented (US 20080153932 A1, 2007).

Case: DENSO Manufacturing (UK) - Matchmaking initiative NISP (National Industrial Symbiosis Programme - NISP, 2012), objective: support DENSO Manufacturing in finding more sustainable waste treatment.
DENSO Manufacturing (UK) is manufacturing 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 was keen to identify a more sustainable option that required less transportation and offered greater environmental benefits. DENSO Manufacturing UK attended a number of NISP 'Resource Matching' workshops. They further benefitted though on-site visits and practitioner support. 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 22), making it suitable for use in an 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 of waste filter cake by drying it and reducing moisture content of the cake;
- Cost saving of £5,000 (€ 6,600) as a result of waste minimization (reduced quantity of cake to be disposed of) and transport;
- Road transport requirements were reduced by 200 miles per year (CO_2 reduction).

Figure 22: DENSO filtercake (NISP, 2012)

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

Manufacturing band saws require grinding operations which generates waste. This waste consists of grindings, mineral oil (coolant) in the form of a cake (Figure 23). Initial this grinding cake was treated as hazardous waste. The concentration 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 23: 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 24) 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 25).

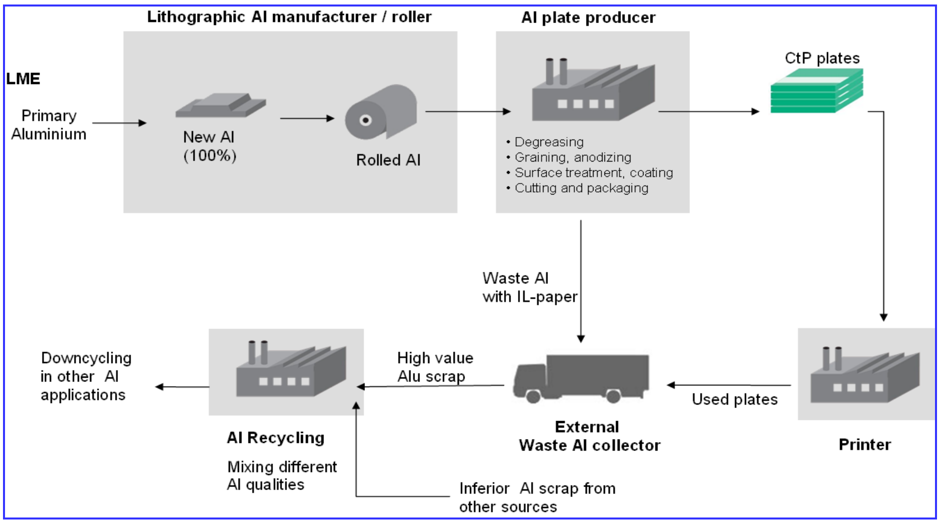

Figure 24: Agfa's old scrap flow (Pellegroms, 2015)

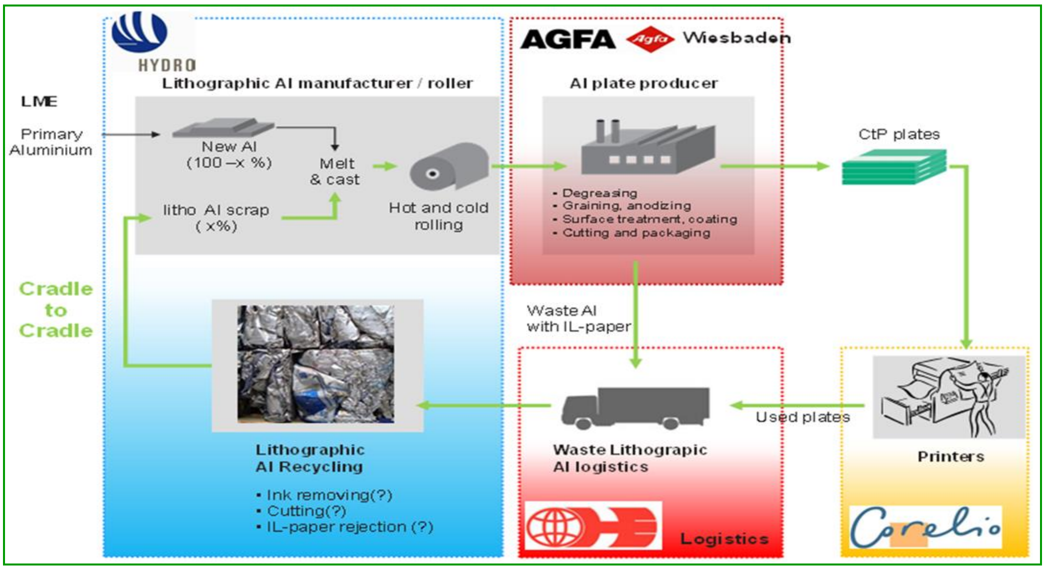

Figure 25: Agfa's new scrap flow (Pellegroms, 2015)

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).

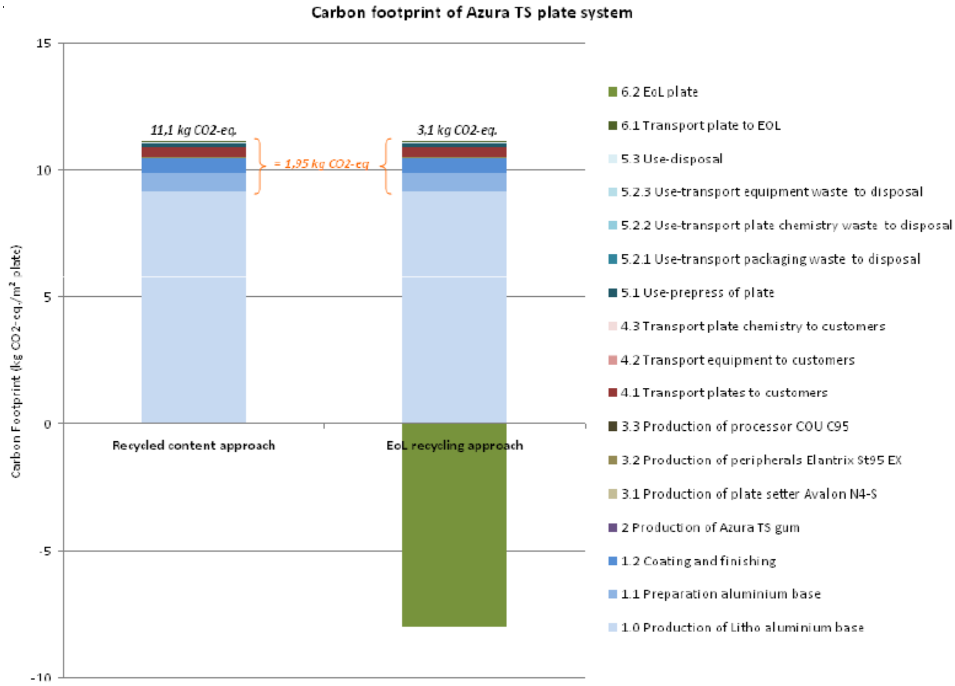

Figure 26: Carbon footprint Agfa (Verschave, 2012)

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-emission has decreases with 15 000 tonnes per year, a net decrease of more than 40% of total CO_2-emission 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.

Applicability

Searching for cross-sectoral and value chain collaboration has an inherent risk. Not all projects result in economic success stories. Business change can and will never happen overnight. New practices are often taken on as pilot projects, prototypes or incremental tweaks, testing the water for a wider rollout if the numbers stack up and others are on board. (Ellen Macarthur Foundation, 2015). Such an iterative approach and search for different partners, processes etc. always result in increased knowledge and extended network partners.
Critical factors for cross-sectoral and value chain collaboration are (Ellen Macarthur Foundation, 2015):

- The willingness to explore paths for collaboration and to take risk.

However, existing funding schemes in several EU countries contribute to overcome this barrier;
- Logistics and approximation of companies.
  They are after all an important cost factor;
- Clear agreements about intellectual property (IP) between all involved actors (providing company, receiving company and intermediate actors);
  Typical questions to be answered are: Who owns the technology? And who can further commercialize this technology?
- Clear and common targets to ensure a win-win situation for all partners;
- Flexibility to change in partner selection, based on gathered insights and knowledge.

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).

AGFA was able to reduce the volatility of price of their aluminium material by closing the material loop.
For the reuse of waste from powder coatings the economic viability depends on quality of the waste and the type of collaboration. For high value reuse options (like production of new powder coatings), the Fabricated Metal Products companies will not pay anything for removing their waste, this is in contrast to traditional collection, for which they have to pay up to 450 €/ton (without transport cost) (Spooren, 2012).

Driving force for implementation

The main driving forces for cross-sectoral and value chain collaboration are an increased efficiency of resource use leading to an overall cost reduction, an increased environmental performance and better business reputation. The collaboration initiatives also result in significant knowledge acquisition and increased resilience by the extending partnering network.

Reference organizations

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).

Harvestmap (Oogstkaart in Dutch) is a new 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. Oogstkaart is currently

(2015) in Beta version as they are continuing to improve the platform, making sharing resources become even more simple. Registration is required.

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.

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.

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

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/

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/

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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2.2.4. Chemical leasing & Chemical management services

Description

In a circular economy, equipment and utilities (electricity, natural gas, water, etc.) are to be used as efficiently as possible. Companies in the Fabricated Metal Products sector are characterized by a high use of resources, especially of raw and auxiliary materials.. Efficient use of resources will lead immediately to several environmental and economic benefits. Chemicals (solvents) for example are extensively used in the sector for various applications, e.g. degreasing, cleaning and coating. A proven best practice for an increased efficiency of the use of chemicals is changing from buying chemicals to buying the functionality of the chemicals (degreasing, cleaning, coating, etc.). Chemical leasing (ChL) and Chemical Management Services (CMS) are examples of this concept.

ChL:

Instead of the conventional business model of buying and disposing of products, i.e. chemicals, companies can lease these products as, after all, they are only interested in the functionality of the chemicals. From a supplier's perspective there is a shift from the idea of providing / selling the chemicals towards the idea of providing the functionality, e.g. number of square meters degreasing /de-oiling. Within the concept of ChL, the suppliers will sell square meters of cleaned surface or number of parts cleaned instead of a certain quantity of chemicals. From a user's perspective, ChL will lead to reduced costs and risks, while maintaining the quality and reliability. An important aspect of ChL is that both suppliers and users become partners with common incentives or targets, which is different from the traditional business model. In the traditional business model, the supplier is interested in selling as much chemicals as possible, while the users want to reduce the amount of chemicals used (Figure 27). Another important difference with the conventional business model is that ChL makes the suppliers in charge of the (re-)treatment of the used chemicals. In fact, in the conventional business model the users of the products are responsible for disposing of the chemicals, while in the concept of ChL, the suppliers take care of that. Within the concept of ChL, suppliers and customers have the same benefits, i.e. both are triggered by a reduction of energy use, resource efficiency, etc. Companies offering ChL often provide also their knowledge to select chemicals and technologies (to use these chemicals) with the highest performance (for the specific case) and the lowest environmental impact. E.g. chemicals with the appropriate characteristics for the materials treated, reduce the energy consumption of the processes where chemicals are used. The involvement of the suppliers differ from case to case.

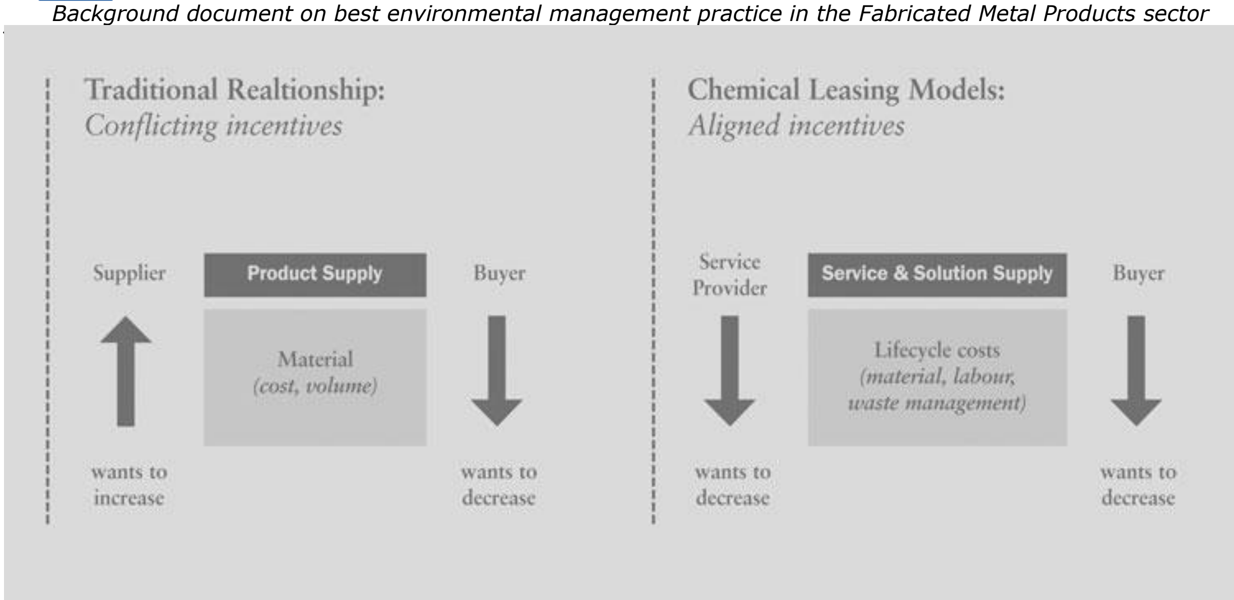

Figure 27. ChL business model compared to the conventional business model (Dow Safechem 2015)

Apart from the aligned interests of suppliers and consumers, ChL will also lead to several other benefits. Invoicing for example will be based on a product performance parameter like parts cleaned or life-time of the solvent[29] instead of the quantity of solvent used. Furthermore, ChL will trigger the optimization of cleaning processes by steering the process and lead to an enhanced pooling of know-how within a service alliance throughout the entire value chain.

CMS

There is no exact definition of CMS. In a CMS business model the supplier of a chemical offers a series of chemical related services, like pollution monitoring, maintaining MSDS, personnel training, laboratory works, etc. The range of chemical management services varies considerably.

Chemical Management Services are similar to ChL, but do typically not include the equipment (capital goods) to perform the cleaning operations. 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: high level inventory, chemical usage and related costs;
- Look for partners (ChL or CMS) based on processes, type of chemicals, amount of chemicals and related cost;
- Set the baseline for chemical cost: map of life cycle stages & organizational functions, cost analysis (over all life cycle phases of the chemicals);
- Develop an action plan: prioritisation of products and processes, case studies (scenario analysis), identification of performance measures;

[29] The Fabricated Metal Products company will sell a “service” e.g. availability of a certain solvent X with quality Y. The supplier of the solvent will choose his own strategy to fulfil these requirements (e.g. changing the solvents when needed, or provide a solvent regeneration unit, etc.).

- Further engage partnerships: stakeholders analysis, service providers, business case, definition of roles and responsibilities.

Difference between ChL and CMS

There are only few differences between the two business models. Payments can either consist of a fixed fee or be quantified (like in the ChL model) in functional units.

The main difference is that the services offered in a ChL model focus on the optimization of the application process of a certain chemical, while CMS may encompass many other services. These services often concern the full pallet of chemicals used in a company that may not all be provided by the company offering the CMS. In the context of ChL, on the contrary, the company offering the services also supplies the chemical(s) it offers the services for. (Chemical Leasing, 2015)

Achieved environmental benefits

The most important benefit of ChL, compared to the traditional business model, is that it lead to a more efficient use, and therefore a reduction in the amount, of chemicals used and disposed of. Other important benefits of ChL are:

- Knowledge enrichment, needed to optimize 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.);
- Avoiding of redundant chemicals;
- Stimulation of substitution of hazardous chemicals;
- Reduction of customer’s chemical waste (up to 10%, see Figure 28);
- Avoidance of underutilized chemicals, especially among small to mid-sized companies;
- Reduction of chemicals used (10 to 30% -see Figure 28);
- Reduction of energy used (due to less cleaning cycles, storage of chemicals, up to 10% ; -see Figure 28);
- Reduction of the water use (due to less cleaning cycles, up to 25% -see Figure 28).

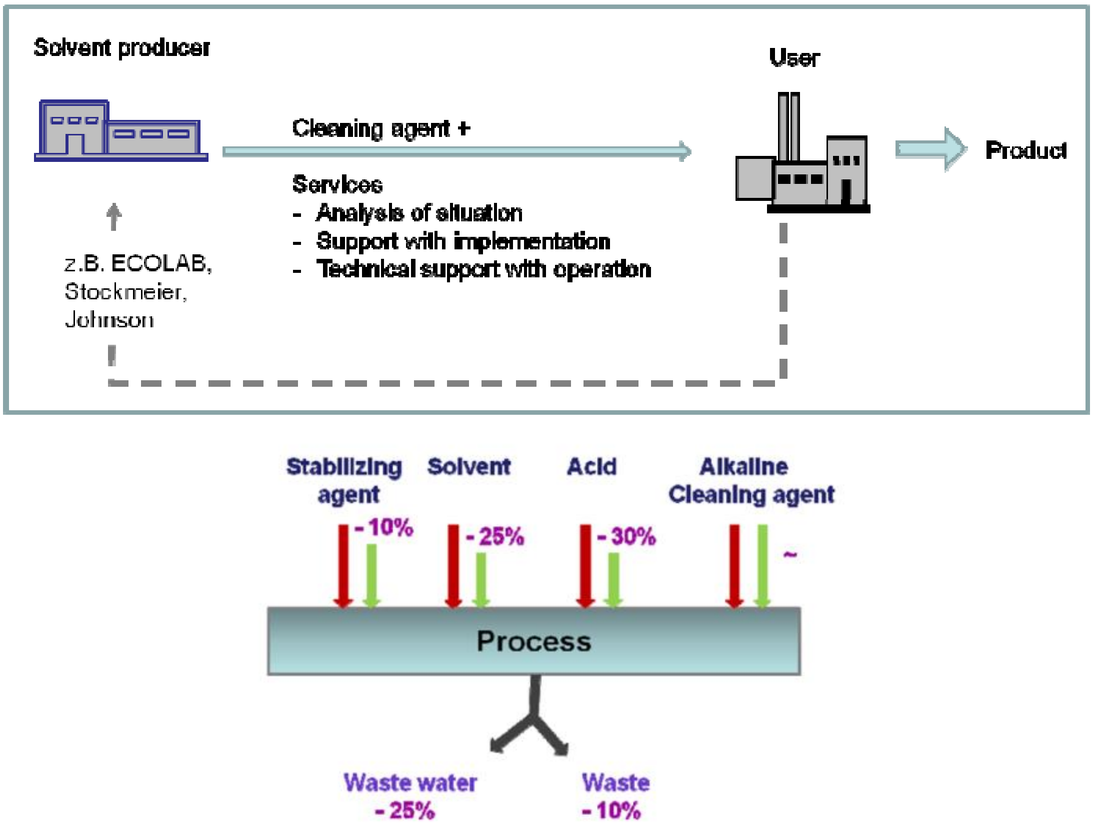

Figure 28. Case study illustrating the potential of ChL (The Guardian, 2014, based on data from Ecolab, Stockmeier, Johnson).

Appropriate environmental indicators

Appropriate environmental indicators for ChL are:

- Use of solvents or chemicals, typically expressed as amount of chemicals used per part cleaned or amount of chemicals used per m² cleaned;
- Emission of VOC, typically expressed as amount of VOC per part cleaned and related health and safety risks;
- Health and safety risk can be evaluated by performing a risk assessment before and after implementation of ChL, and a comparison of initial and residual risks (Yes/No).
- Energy use for processes related to the use of solvents or chemicals, typically expressed as number of parts cleaned per kW.

Cross-media effects

There are no cross-media effects due to the implementation of ChL. The responsibility for disposing of and (re-)treating used chemicals shifts from the perspective of the users to the suppliers.

Operational data

In the Aircelle Ltd (Burnley, UK) case, ChL was implemented. 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. The services provided resulted in a 10% reduction of solvent consumption. Additional, the machine utilisation went to 99%, due to a better supply of chemicals. Compared to the initial situation the company's annual solvent consumption dropped by 92.7%, and a reduction of energy cost by 50% was realized. Additional financial advantages were obtained thanks to reduced administrative costs, the supply matching exactly the needs avoiding mitigation actions for short falling, etc. (Dow safechem, 2014).

At BAE Systems (Samlesbury, UK) ChL and new cleaning equipment led to a solvent reduction (trichloroethylene) from 5 ton to less than 0.5 ton per annum (i.e. a 90% reduction) (Dow safechem, 2012).

Applicability

ChL can be implemented in companies using chemicals for various applications, e.g. degreasing and cleaning. ChL will be mostly beneficial for companies using solvents and chemicals with a high environmental impact.

All companies using a large amount of chemicals (primary and secondary chemicals) can minimum apply a CMS.

Without strong support of the company's management, it can be very difficult implement ChL. All company levels must be involved in the implementation. A lack of knowledge about possibilities offered by suppliers, can also pose a problem. The implementation of ChL can further be hindered by the lack of credible, independent information on the benefits of ChL.

Economics

ChL will lead to a more efficient use of chemicals, and therefore the total costs related to the use of chemicals, including transport costs, will be reduced.

ChL reduces the high transport costs of buying loads of chemicals from few suppliers (on average 65-75% of all chemicals purchased are from manufacturers/resellers who supply 1-3 line items).

ChL is nowadays widely used in the automotive, aerospace and microelectronics sector. The environmental benefits observed here include reduced chemical use, reduced emissions, and reduced waste generation, as well as substantial cost savings. A total average cost reduction of 30% has been achieved in the first five years (EPA, 2012).

Driving force for implementation

Several driving forces for the implementation of ChL can be identified:

- Risk reduction (HS&E);
- Cost saving;
- Broader knowledge of cleaning processes by partnering with chemical suppliers

Reference organizations

The following companies in the Fabricated Metal Products sector have successfully implemented ChL:

Aircelle Ltd. (Burnley, UK): Aircelle Ltd. is the U.K. is a large manufacturer of engines and components applied in the aerospace industry.
http://www.aircelle.com

BAE Systems (Samlesbury, UK): BAE Systems is a large provider of defence and security products primarily for military applications.
http://www.baesystems.com

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

Chemical Leasing provides a list of companies that have implemented ChL and the benefits they achieved. The list is available on: http://www.chemicalleasing.com/sub/pilot.htm.

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2.2.5. Energy management

Description

The initial steps in developing an effective energy management strategy involve assessing the drivers of an organisation's energy consumption, monitoring its energy usage, and identifying areas for improvement. Actions will then be deployed to reduce energy demand (through energy efficiency measures) and reduce the impact of energy supply

Some Fabricated Metal Product manufacturing processes tends to be especially more energy-intensive than other, however, a holistic investigation of the energy flows throughout a facility can help achieve significant savings in energy resulting in both cost and GHG emission improvements. This cross-cutting BEMP does not aim to develop specific process solutions relevant to individual process (some of which are developed later in the document) but rather to outline the range of energy efficiency solutions which should be investigated to achieve best practice.

An energy management system (EnMS) can be based on a standardised or customised form. Implementation according to an internationally accepted standard can give higher credibility to the EnMS and also open up opportunities for gaining certification against certain industry standards. The purpose is similar to that of establishing an environmental management system (EMS), but with a clear emphasis on energy consumption.

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

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

Table 17 shows how best practice measures can be distinguished from good practice and fair practice, when considering each of the above aspects.

Table 17. Energy management matrix

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

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

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

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

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

Achieved environmental benefits

EnMSs are useful where incremental gains are being sought through process refinement and efficiency measures, without requiring radical redesigns of the process. While the energy savings brought about by each individual measure are typically small, the cumulative savings can be substantial. Organisations with a poorer starting point may achieve more significant short-term improvements, but there are typically opportunities still available even for firms that are relatively advanced in their techniques.

Appropriate environmental indicators

Appropriate environmental indicators are:

- Energy use (kWh_e and KWh_t /year; / month, / week);
- Monitoring system for energy use – Y/N.

Cross-media effects

Energy management should be integrated with other environmental objectives and consider the overall environmental impact. It should be noted that it may not be possible to both maximise the total energy efficiency and minimize other consumptions and emissions (i.e. energy may be required to reduce emissions to air, water and soil).

Operational data

Detailed examples are not provided in this BEMP but are available for specific BEMPS.

Linked BEMPs are:

- 2.2.6 Efficient ventilation;
- 2.2.7 Optimal lighting;
- 2.2.8 Energy and water savings of cooling circuits;
- 2.2.9 Efficient use of compressed air systems;
- 2.2.10 Reduction of standby energy of metal working machines;
- 2.3.7 Hybrid machining as a method to reduce energy consumption;
- 2.3.9 Reduce the energy for paint booth HVAC with predictive control;
- 2.3.10 Selection and optimization of thermal processes for curing wet-chemical coatings on metal products.

Applicability

Energy efficiency solutions can be deployed in all facilities, from incremental to in-depth refurbishments. Regular walk-rounds are also recommended to identify new sources of energy waste even in facilities that have already been optimized.

Economics

Detailed examples are not provided in this BEMP but are available for specific BEMPS.
In case of refurbishment or new production line, it is important to look to the total lifetime cost rather than to investment costs.

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 literature

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2.2.6. Efficient ventilation

Description

Ventilation is an important 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. Ventilation for painting processes (paint boots) requires specific measures as described in §2.3.9 (Reduce the energy for paint booth HVAC with predictive control).

In a Fabricated Metal Products company, the most efficient methods of controlling contamination in the occupied zone of the welding shop, and particularly in the breathing zone of the operator or welder (with a manual welding), are:

- Enclosure of exhaust from the total welding process when automatic welding machines are used;
- Enclosure of exhaust from the welding area enclosure when robotic welding and material handling are used;
- Installation of local exhaust which captures the contaminants at or near their source.

No local exhaust system is 100% effective in capturing fumes. However, it is important to note that capture efficiency has a greater influence on air quality than filtration efficiency. No filter device is effective until the fume is drawn into it. In addition, there will be circumstances, because of the size or mobility of the welding zone, where installation of local exhaust systems 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 system and to dilute fumes generated after welding. General ventilation systems supply make-up air to replace air extracted by local and general exhaust systems. Also, supply air is used to heat and cool the building. The volume of outside air to be supplied by a general ventilation system should exceed the volume of air exhausted by local ventilation systems. Buildings should be pressurized to prevent air infiltration creating cold drafts in winter, and hot humid air in summer. In addition to a local exhaust system, a general exhaust system is used to evacuate air from the building.
Special attention should be given to ventilation of areas with grinding and polishing operations. Especially, in the case with aluminium production. 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).

To reduce the energy consumption of ventilation, different steps have to be taken[30]:

1. Understand the building and its air flows;

[30] Ventilation must been seen as a part of the global HVAC (Heating, Ventilation and Air Conditioning) of the building, where a comparable approach is advisable.

2. Make an overview of sources of heat, humidity and pollutants (dust, fumes, etc.) in the building;
3. Reduce emissions where possible;
4. Define the actual (and future) needs for ventilation;
5. Audit, to compare the defined needs with the current installation;
6. (Re)design the ventilation.

The installation of a ventilation system requires a profound study of the features of the manufacturing site, the buildings and the processes installed. In particular, a good understanding of the manufacturing site and the buildings ensures a satisfactory air quality. Elements such as design, physical layout, mechanical systems, equipment and installed manufacturing processes (the kind of installed manufacturing processes plays an important role as well) and space usage are all essential and can affect air quality. Furthermore, the air distribution system requires particular attention. The following questions should be addressed, with care, in advance: "How does outdoor air get in?", "Is the air filtered?", "How does air circulate throughout the building?". It is also important to understand how spaces are designed and where walls (also knowing the building materials and their thicknesses), furnishings and equipment are located. Nevertheless, it should be mentioned that the building layout can create physical barriers that impede the flow and distribution of air, which can impact the quality of air in a given area (TSI, 2013).

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 sector. Open water systems, which can cause humidity problems are limited, but a lot of process causes emit chemical products, which enter the air as aerosols or vapour (e.g. the finishing step). Before defining the needs, several methods for managing a pollutant source, are available once the source is identified, 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;
- Minimizing 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.

After the reduction of the ventilation requirements, by reducing of the sources of pollution, the ventilation needs can be defined more precisely. However, the definition of the ventilation needs should take into account actual legislations and standards [31].

After the precise definition of the ventilation needs, auditing can start. In certain cases measurements of the air quality may be needed.

[31]. For instance, the EU directive (2010/31/EU) on the energy performance of buildings and the WHO guidelines on indoor air quality (2010), are the most important policy instruments that should be taken into account when the ventilation needs are defined.

The last step is to design (or re-design) the ventilation system. To reduce the energy use following techniques must been considered:

- Using variable speed drive motors for ventilation;
- Optimizing position and orientation of blowers;
- Controlling the air volume in function of the ventilation needs.

Often systems are designed in a way that enables ventilation from multiple (similar) workstations all connected to one dust collector, filter and fan. Correspondingly, the appropriate 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 (Litomisky, 2006).

These on-demand systems are already being used in the chemical, metal, and woodworking industries, achieving average electricity savings of 68% over unregulated, classical systems. The basic idea is simple: equip each workstation with a sensor that detects when ventilation is necessary, and use a motorized gate to close the ventilation duct when ventilation is not necessary. Then the RPM of the fan can be adjusted to achieve a proper air volume in the ducts.

If dust or other material 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 RPM of the fan accordingly, and it also opens additional gates at non-working machinery if this is necessary for maintaining proper air velocity.

Ventilation can be regulated by monitored demand, configuring the machine shop operations such to avoid peak draws and more energy efficient operation. Installed venting capacity can be optimized taking the effective need into account instead of an on/off regulation. Demand data capture and controls on plant level demand requires side wide coordination. The dimensioning of the venting installation based on the effective demand. Comparing utilities demand over time with utilities cost curve allows for total cost of ownership reduction.

Lowering the air extraction volume reduces also the need for heating or air conditioning in the plant. This generates additional environmental benefits (less energy for heating or air conditioning needed).

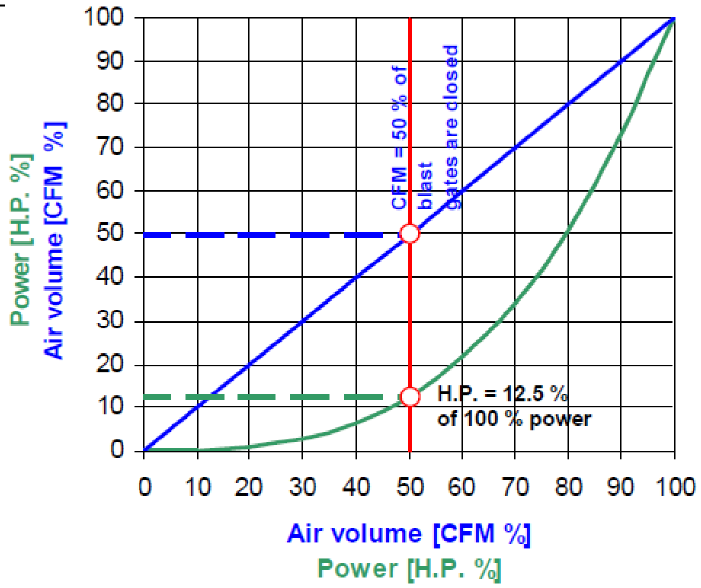


Figure 29. Fan Law: at 50% reduction of air-flow (which is achieved by automatically closing gates on non-operating machinery), fan motor will consume only 12.5% of electricity of what is required when suction is running at all workstations. This is a reduction of 87,5% (Litomisky, 2006)

Achieved environmental benefits

The major benefit is the reduction of energy use. This leads to an overall reduction of the indirect greenhouse gases (GHG) emissions of companies in case the electricity is coming from conventional power plants (from fossil fuels)[32].
By implementing this technology, companies will reduce their direct energy use for ventilation with 20 to 70% (Figure 29, Schlosser, 2011).

In addition, the implementation of demand management processes provide better insights in real ventilation extraction needs resulting in down sized installations. Not all workstations or machining processes operate at 100% during the total shift time. Hence, a well-controlled ventilation results also in a better indoor air quality. Furthermore, it can also reduce energy consumption for heating during winter and cooling during summer, as less air is extracted from the production halls (Siemens, 2010).

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.

Appropriate environmental indicators

Appropriate environmental indicators are:

- Type of ventilation system: demand driven – Y/N;

[32] The energy mix of each company might be different, hence should be carefully examined.

- Use of energy per m³ building (installed kWh or m³/hour): dimensioning of installed ventilation capacity. The capacity can be compared before and after implementation of demand driven ventilation.
- The effective air volume extracted from the building. This can be measured and compared over time periods or production batches.
    - Extracted air per hour (m³/h) or per shift is a good indicator in case of a rather stable production process and volume.
    - Extracted air per produced batch of material X, Y, Z produced (m³) is a better indicator in case of a variable production process and volume.

Cross-media effects

There are no cross-media effects due to efficient ventilation in manufacturing plants.

Operational data

Each workstation must be equipped with a sensor and an automatic air valve. The sensor will detect if ventilation is needed or not. To control the ventilation, all the valves will be steered by a central process unit.

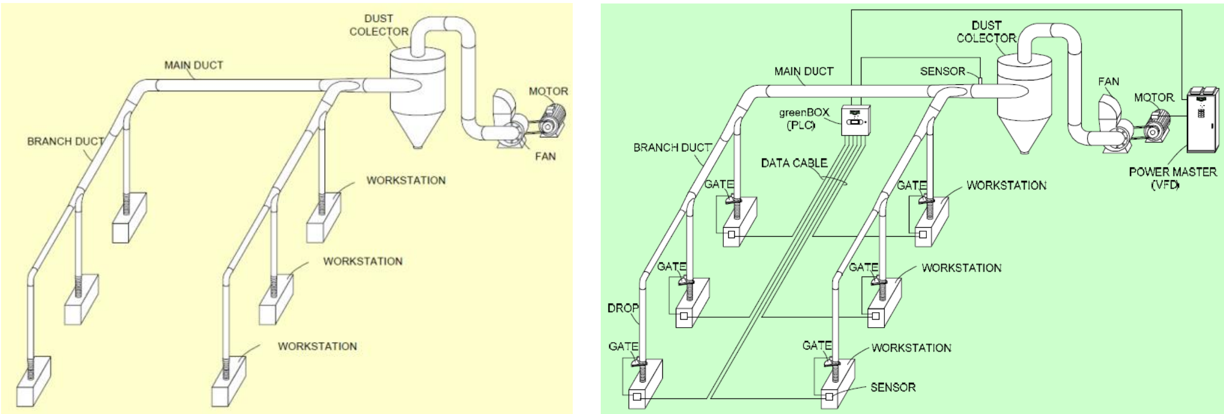


Figure 30: Left: Unregulated system with duct system directly connected to dust collector, fan-motor combination. Right: On demand system with sensors to close duct gates. VFD controlled fan motor controlled by PLC (Litomisky, 2006)

A minimum velocity in the duct is required to prevent dust particles settling in the duct (instead of in the dust collector). The pressure drop needs to be controlled and a process unit adjusting fan speed and/or opening/closing additional gates to assure a proper air speed needs to be installed.

The 'Duct Optimizer software' exist is available to simulate and optimize the duct system for any given application.

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).

Case study: NE08 (BE): upgrade of the ventilation system at a welding training centre building (Acuna, 2014).

Technologies implemented:

- Demand-controlled ventilation strategy with intelligent system controls;

- Current transformers (to detect welding booth operation);
- Motion detectors (to detect welding booth occupancy);
- Pressure sensitive mats;
- Variable frequency drive fan motors;
- High efficiency fan motors.

The ability of the system to adapt to the variable extraction/make-up air demands offers the possibility for energy savings. The new system will enable the reduction of both extracted air volumes and make-up air volumes. Less air to move means less electricity required to operate extraction and make-up air unit fans. In turn, less natural gas will be required to heat the make-up air during colder months. GHG emissions reductions will result from lower electricity and natural gas consumption.

Total energy savings reported (measured, normalized savings after a few months of operations):

- 6,500 GJ/yr of natural gas;
- 800,000 kWh/yr of electricity;
- 9,500 GJ/yr or 2,550,000 eKwh/yr of total energy conservation per year;
- 150 kW reduction in electricity demand.

Case Study – Aerospace Component Manufacturing Plant – demand control ventilation combined with other energy efficiency improvements (Rappa, 2012).

Analysis:

- Manufacturing make-up air and exhausts analysed;
- 150,000 – 250,000 CFM of makeup air supplied and exhausted annually;
- 1,700,000 kWh, 32,000 mmBTus, $435,000 annually;
- 4-7 air changes per hour.

Energy efficiency improvements:

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

Results:

- 1,100,000 kWh, 17,200 MMBtus.

Applicability

This BEMP can be installed in all manufacturing processes in the Fabricated Metal Products sector:

- Forging processes;
- Welding processes;
- Paint spray processes (paint booth) - finishing[33] -(see §2.3.9: Reduce the energy for paint booth HVAC with predictive control)
- Machining.

The installation of an on-demand system is more complex than a conventional ventilation unit. The investment costs and maintenance cost are higher than for a

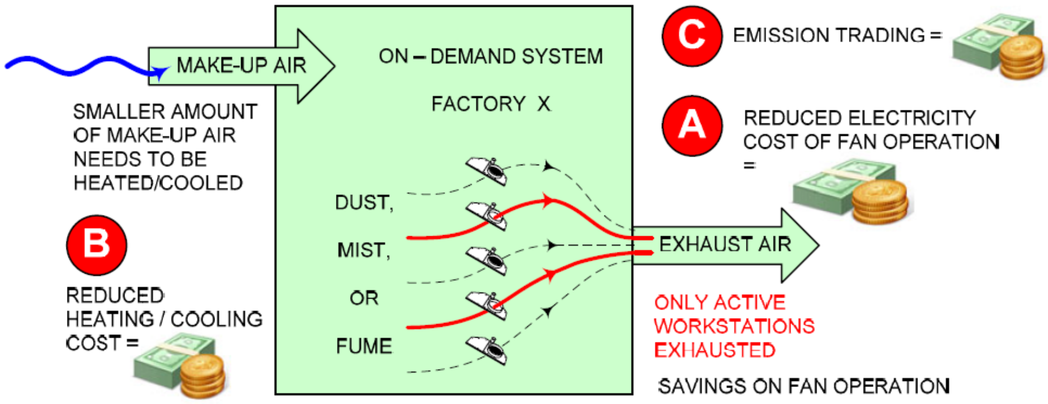
[33] BEMP Reduce the energy for paint booth HVAC with predictive control, is more specific.

conventional system, as it needs steering, sensors, etc. An on-demand systems is easier to implement in new facilities, but also applicable for existing facilities.

Economics

Savings through lower need of heating or air conditioning are typically two times higher than the fan electricity savings (depending on geographical location, operating hours and energy cost) (Litomisky, 2006).

Reduction of energy cost: 20 to 80% compared to on-off non demand controlled ventilation (Litomisky, 2006; Siemens, 2010 and Schlosser, 2011).



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

Figure 31. Savings by on-demand ventilations (Litomisky, 2006)

Case NE08: upgrade of the ventilation system at a welding training centre building (Acuna, 2014).

Savings:

- At 2014 energy rates: $150,000 per year (including demand charges);
- Note: There are also approximately $5,000 to $10,000 per year of predicted maintenance cost savings and an unknown $ figure for shielding gas cost savings.

Case Study – Aerospace Component Manufacturing Plant – demand control ventilation combined with other energy efficiency improvements (Rappa, 2012).

Savings:

- Annual savings: $230,000;
- Payback time: less than 2 year.

Driving force for implementation

The main driving forces for implementation are:

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

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2.2.7. Optimal lighting

Description

Metal products fabrication requires, just like any other industrial process, light e.g. for the product quality check process and safety reasons. The energy consumption for the light system of a production hall is a significant contributor to the overall energy consumption (significance of the contribution depends on the energy intensity of the other energy consuming activities in the company). Energy needs for lighting increases e.g. by increasing operating hours (two or three shifts) or surfaces, and when using older lighting technology (e.g. high pressure sodium lamps). In some Fabricated Metal Products companies lighting is responsible for 10% of the total energy consumption (Dialight, 2015).

Optimization of existing plants can be an opportunity to reduce costs and the carbon footprint.

To reduce the energy consumption of lighting, different steps have to be taken:

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

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

A *lighting study* 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 latter is defined in standards EN 12464-1 (indoor) and -2 (outdoor) (2011). 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 gives also an overview of the light duration for each location (e.g. minutes for corridors, only when people pass, or the whole day for workspaces).

During an *audit* a comparison between the defined lighting needs and the actual lighting will be done.

A *lighting plan* gives the optimal solution (e.g. amount of luminaires and luminous intensity) for each location in 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 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. Taking 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 the luminaire including light source, ballast and optic;

- the choice of an emergency escape lighting system;
- the installation and commissioning of the whole system;
- lighting control system;
  - Lighting control is available for almost all lighting applications and some examples are listed below.
    - daylight dependent lighting control;
    - movement dependent lighting control;
    - constant illumination level;
    - building management system;

    In this system light and energy control is integrated at building level. For instance a system that can simultaneously apply six 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.

Different economic models are possible to finance relighting projects. Fabricated Metal Products companies 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.

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 (CO2) 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. 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 (Encon, 2015) give savings potentials for electricity of 50% to 80% based on cases studies in different industrial sectors.

Appropriate environmental indicators

[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. The study is carried out for the European Commission, DG Energy under specific contract N° ENER/C3/2012-418 Lot 1/06/SI2.668525, implementing framework contract ENER/C3/2012-418 Lot 1. The study team effectively started in January 2014 and is expected to be finished in December 2016. The draft only contains a quick scan for the whole industry. Later, detailed study will be made for some subsectors in the industry.

An appropriate environmental indicators is the electricity consumption (e.g. in kWh/m² lighted floor per year) for the lighting of the Fabricated Metal Products company is a general indicator.

Cross-media effects

Based on measurements, 98% of the lighting in workspaces is insufficient comparing to the EU standard. When the original lighting installation is not in line with the actual standards on Lighting of work places, more light can be needed (Technische Unie, 2015). Besides better lighting, relighting can lead to more light. Thus, the overall result can be a better lighted company, without energy savings.

Operational data

The total consumption of electricity 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 (DE)

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 year (ETAP, 2011). In other companies, new light systems lead to comparable reductions (50% at John Deere, 60% at Verhoef; Philips, 2011 and 2015). 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 (ES), producer of metal pieces (Dialight, 2015)

With the metal processing machinery pumping so much energy, the 32 x 400 W high pressure sodium (HPS) lights in the 1288 sqm Martisa facility were subject to frequent dimming and flickering, so the management were looking for 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.

Under 150W DuroSite LED High BaysUnder 400W High Pressure Sodium lighting 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.

Martisa is now enjoying the immediate benefits of 69% reduction in lighting energy consumption and reduced carbon emissions from solid-state LED High Bays that suffer no flickering or dimming effect from the amount of energy being pumped by the machinery. 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. Carrying a 5-year continuous performance warranty and with an expected lifetime of 60,000 hours, the LED lighting has also greatly reduced the maintenance burden and cost.

Case Study: Olympus KeyMed (UK) - producer of metal medical equipment (Dialight, 2015)

Olympus KeyMed's Southend-on-Sea facility comprises warehousing and manufacturing with sheet metal as well as a paint shop. Here it not only produces medical and industrial products, but it is also the sole UK point of importation and distribution of all Olympus products. With over 100 metal halide high bay lights across our 3,380 square metre facility, measurements shows that the 400 W high bays were actually operating at 440 W and accounting for 10% of our 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. Additionally there was the ongoing chore of inspecting for failed lights and servicing those that had failed.

After researching the LED market, and with the recommendation of energy consultants a lighting plan was made. Mounted at a height of 12 m, the metal halide high bays were replaced one-for-one with 150 W LED armatures. Significantly this led to the discovery that the actual consumption of the LED lights including drivers was 5-10% less 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.

In 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 periods of less than 4 years.

Re-strike time had been an issue in all areas with the metal halide lights, especially in the inspection area, so low level fluorescents had been installed as back–up to avoid production downtime. With the instant-on ability of the LED High Bays these back-up lights can now be taken out.

Applicability

The applicability of optimal lighting is generally applicable in all Fabricated Metal Products companies. The potential impact increases with duration of the light needs.

Economics

Economics highly depend on the size of the relighting project. The GreenLight programme[35] (EU, 2015) provides calculation spreadsheets[36] for assessing the cost-

[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 when (1) it is profitable, and (2) lighting quality is maintained or improved. GreenLight was launched on 7 February 2000 by the European Commission Directorate General Energy & Transport.

The objective of the GreenLight programme is to reduce the energy consumption from indoor and outdoor lighting throughout Europe, thus reducing polluting emissions and limiting the global warming. The objective is also to improve the quality of visual conditions while saving money.

[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

effectiveness of one (or two) energy-efficient lighting system(s) compared to one conventional new installation. Other companies provide comparable spreadsheets (Energie+, 2015).
Different economic models are possible to finance relighting project. Fabricated Metal Products companies 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.

In case sector companies invest in relighting, 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). The payback time depends on the original situation.

The service supplier of 'light' has the incentive to reduce the lighting cost for its client (mainly through the same or higher light performance for a lower energy cost) on the one hand, and to design/search for lightning 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.

An example of servitisation: In the CycLED-project (2015) a case was elaborated in which, by changing 'classic' illumination through LED-technology, over a period of 12 years, costing 208 099 euros on the service contract (all materials and services included) (the classic illumination would have cost 320 152 euros in the same period). This is a yearly saving of 35% on operating costs. Moreover, through higher energy efficiency of the chosen technology, with constant energy cost, an extra of 112 053 euros could be saved (146 374 euros with the projected 5% increase of electricity prices per year).

Driving force for implementation

Increased energy costs for companies make relighting an increasing interesting option.
The light quality is increased, having a positive effect on working behaviour of employees (Schlangen et al, 2014). In case of servitisation of lighting, companies can focus more on their core activities, reducing risks and resources dedicated to lighting optimization.

Reference organizations

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.

Black & Decker – producer of do-it-yourself tools
They got the European GreenLight Main Endorsers certificate for the relighting of their distribution centre.

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 – world leader in agricultural technology
The company 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).

Volvo Cars - productions of cars and trucks.
In their production plan in Ghent, a relighting is been done: 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)

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2.2.8. Energy and water savings of cooling circuits

Description

To optimize cooling circuits and reduce the energy used a systematic approach is necessary:

1. Define the actual (and future) needs for cooling, reduce the demand where possible;
2. Audit, to compare the defined needs with the current cooling installation;
3. (Re)design cooling installation.

Below the approach is described for the machine shops, as cooling circuits in machine shops are often passed on water circuits.

Step 1: Define needs and reduce the demand

- If the primary needs can be reduced by selecting other machining, pumps, etc. then this has to be done in the first step. For instance, over-specified fixed seed pumping capacity versus demand driven (VFD) pump capacity control.
- Largely abandoning the use of cutting fluid (e.g. minimum quantity lubrication) is unfortunately not often achievable due to quality issues. However, optimizing spray nozzles for grinding and reducing the cutting fluid pressure for internally cooled drilling and milling tools is often possible.
- Usually, the cutting fluid supply continues during downtime so that the machine can maintain a steady temperature. The machine is therefore extensively flooded with cutting fluid. By optimizing the restart process and improving scheduling, temporary shutdowns are made possible. This is linked with BEMP 2.3.3 on cutting fluids**Error! Reference source not found.**.
- Reduce the temperature specifications where possible. When there are large temperature differences between the cutting fluid and its surroundings, the cost of the re-cooling process increases significantly. With oil-based cutting fluids, adjusting the temperature to the room (or ambient condition) becomes an option.
- If the primary needs can be reduced by selecting other machining, pumps etc. this has to be part of the first step. For instance, larger pumps are especially used in central systems and to internally cooled tools. The pressure is usually kept constant by a bypass regulator. Regulating the pump speed (through Variable Frequency Drive (VFD)) instead provides significant savings. Centralized cooling for multiple machines make system optimization possible.
- Last but not least, the total cooling need of the factory is not always the sum of all potential maximum cooling needs. Timechart the cooling need and identify where cooling needs are to be added up and where cooling needs can be flattened out by shifting over time (in particular by looking at what processes are largely dependent on the outside temperature, and which are almost independent of outside temperature). The approach below explains this process.

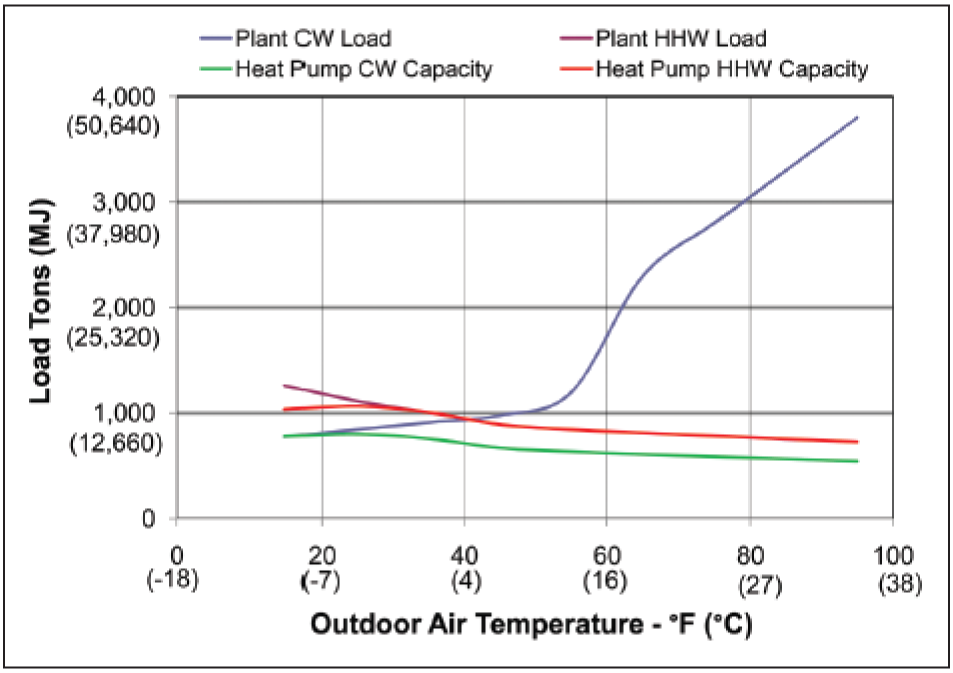

Figure 32. Plant and heat pump load (Heemer et al, 2011)

After the audit step (step 2), the optimum cooling equipment (step 3) must be selected.

- When designing the system, priority should been given to cooling optimization at the machine level instead of cooling optimization at the plant level.
- Avoid designing the system based upon 'standard' cooling equipment. The most energy and water efficient solutions should get preference.
- Select the optimal cooling tower system. Trade-offs need to be made between energy efficiency, water saving and noise reduction. In general, axial fan equipment is more energy efficient then radial fan configurations, while noise-wise the opposite is true. Table 18 gives an overview of the advantages and disadvantages of different types of cooling towers.
- If possible, open water cooling systems should be avoided, as the cooling water can become polluted and needs treatment before discharge.

Table 18. 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	Sound level	Operational safety (Hygiene)	Water saving
Fan type				
Axial fan (forced draft)	more efficient fan types	Reduced speed and specific fan configuration to reduce sound reduce also the energy efficiency		
Radial fan (induced draft)	less efficient fan types	easier to reduce sound (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 less sound effective due to sound of falling water	higher risk on water due to larger supply	low potential for water saving
closed system		potentially lower sound emission		More potential for water savings

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.

Achieved environmental benefits

By using a properly working chilled water system design, the energy and water consumption can be reduced.

By using less water, the water treatment cost can often be reduced. Especially in open cooling systems the water volume to be treated (softening, filtering) is reduced.
Furthermore, the noise level of the system can be reduced significantly, benefiting employees as well as other actors like neighbouring companies, neighbouring families, wildlife (in case of night operations), etc.
In the Bosch metal cutting departments in Feuerbach and Bamberg the systematic approach resulted in a total savings of 4,000 MWh per year (Energiewende180, 2015).

Appropriate environmental indicators

Appropriated environmental indicators are:

- Energy consumption (kWh/year for cooling);
- Water consumption (m^3/year for cooling);
- System optimization versus sub optimal machine level optimization – Y/N;
- Is there a sound reduction? Y/N.

Cross-media effects

Open or semi-open cooling circuits can lead to microbiological contamination. Therefore water treatment and control are needed. Legionella (the bacterium Legionella pneumophila) can grow in the cooling water within the typical temperature range of open cooling systems.
Legionella pneumophila is a ubiquitous organism. It appears in almost every ground and surface water. The organism survives typical chlorine disinfection for potable water and consequently can appear in finished water distributed to homes and industry.

Good practices and guide lines exist to prevent legionella to occur (e.g. Guideline: Best Practices for Control of Legionella from the Cooling Technology Institute) .

Operational data

Adiabatic cooling (Figure 33) based on a classic dry cooler is an alternative that does not provide the possibility for evaporative cooling, but does have advantages over dry cooling:

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.

In the VW plant in Salzgitter VFD drives are installed (Grundfos, 2015). These frequency-controlled pumps offer a number of benefits compared to fixed-speed pumps, in addition to energy savings:

- The frequency converter allows simple wiring procedures;
  This is especially the case when using VFDs with an integrated frequency converter's lower range of pump power, typical available up to 22kW.
- There is no need for energy-consuming transfer ports, line throttling and valve controls to set the duty point;
- Time-consuming adjustment work is no longer required in the event of changes to the production line;

- Remote control and parameter adjustment device can be used to monitor changes (monitors are available on the market) and save current operating states for the individual pumps;
- No pressure surges occur during system warm-up, thanks to soft start technology, resulting in a positive impact on tool lifetime.

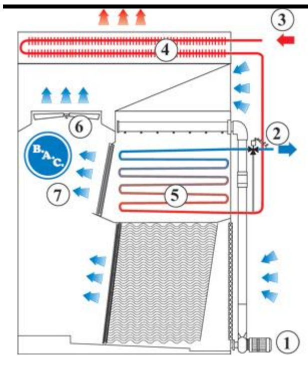	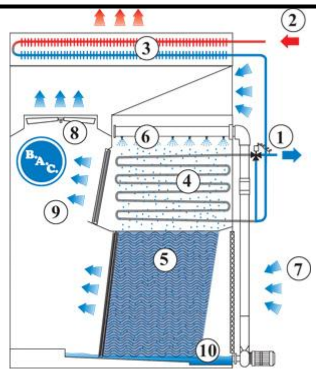	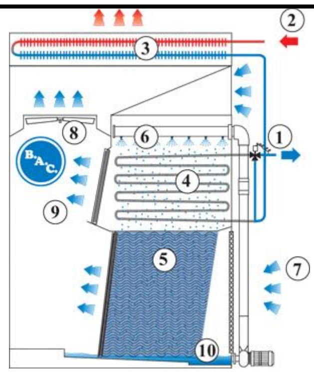
Dry cooling Cooling the liquid by the dry finned coil (2) for example in winter conditions when the outside temperature allows dry cooling.	Adiabatic cooling The fluid is cooled in the dry finned coil (2) but the air flowing over this dry coil is saturated with water which increases the cooling capacity.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

Figure 33. Hybrid systems offers different operation mode: for dry, adiabatic and wet-dry cooling (Baltimore Aircoil, 2015)

Applicability

The approach is fully applicable for all SMEs, but also for large scale companies.

All companies have cooling needs for one or more machines or other applications and processes like forging, etc.

Although the principles and approach for seeking energy and water consumption reductions in the water (coolant) circuits are logical, SMEs might desire support from external partners. For most Fabricated Metal Products SMEs, cooling management is not a high priority. In this context, capacity building via subcontracting is often more attractive than going through a learning curve alone.

Economics

Most of the actions resulting from this approach (cooling needs reductions, controls VFDs, etc.) can be evaluated as separate investments. However, it is important to keep the whole picture in mind to assure that the economic benefits are optimized over the entire system. The economic benefits have to be evaluated over the entire life time.
In general, the investment for hybrid cooling systems is significantly larger than for dry coolers, but the water cost are lower (see Figure 34)

Additional cost for hybrid cooling tower versus water saving:

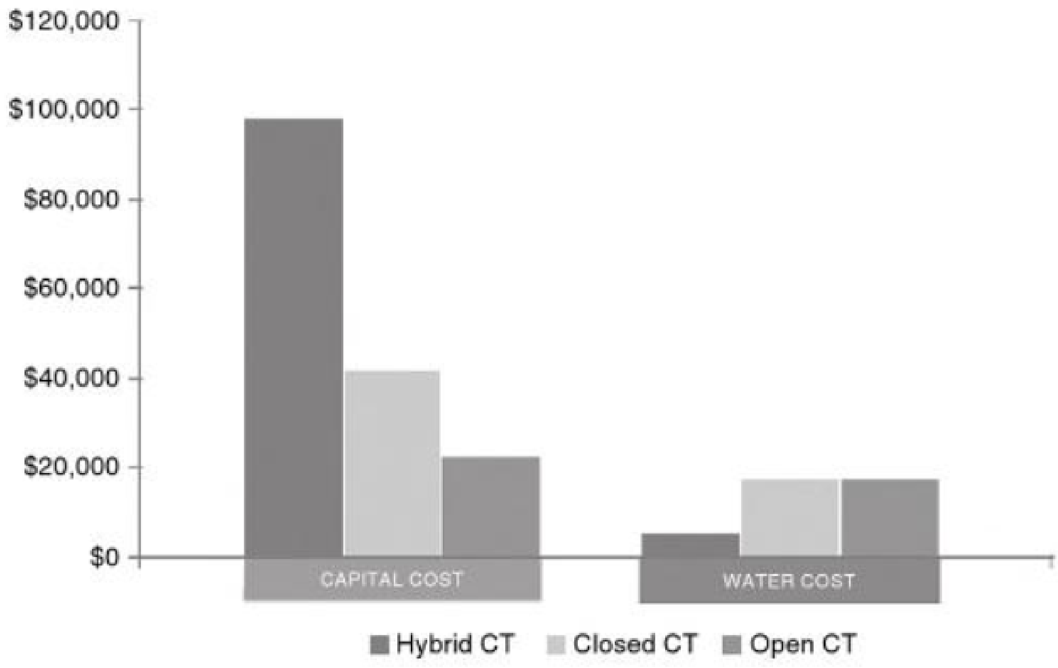

Figure 34. Cost comparison between hybrid cooling towers and conventional wet cooling systems. The comparison is based on a cooling load of 2 030 KW, an inlet temperature of 40°C, an outlet temperature of 30°C and a wet bulb temperature of 274°C (Seneviratne M., 2007 ; based on data of Baltimore Aircoil)

Driving force for implementation

The main driving forces for implementation are:

- Energy savings;
- Water savings, especially under the climatic conditions in south of Europe;
  The climatic conditions in south of Europe will lead to alternative selection of technologies.
- Water scarcity in south of Europe;
- Cost savings.

Reference organizations

BOSCH (http://www.bosch.com/en/com/home/index.php) In the Bosch metal cutting departments in Feuerbach and Bamberg the systematic approach resulted in a total savings of 4 000 MWh per year (Energiewende180, 2015).

Volkswagen is an automobile manufacture. (http://en.volkswagen.com/en.html). In its plant in Salzgitter VFD drives are installed (Grundfos, 2015).

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2.2.9. Efficient use of compressed air systems

Description

Compressed air is a very convenient energy carrier that is widely used in the metal fabrication sector for hand tools, instrumentation, processes, etc. Nevertheless, it is often not the optimal solution in terms of energy efficiency and total cost of ownership. Typically, only 17% of the total energy supplied to the compressor is converted into usable energy (Radgen, website). Compressed air systems often seem interesting because of a low initial investment cost. However, their energy consumption is responsible for 75% of the total lifetime costs.

To optimize the use of compressed air, it is important to take the following elements into account:

1) Elimination of inappropriate use of compressed air;
2) Optimization of the compressed air system configuration;
3) Optimization of the compressed air use;
4) Appropriate maintenance for compressed air systems.

Companies can optimize the use of compressed air based on these elements, in order of enumeration, but might also choose a different starting point.

Elimination of inappropriate use of compressed air

Inappropriate use of compressed air refers to all applications which can be executed in a more effective or efficient manner without the use of compressed air.

Table 19 provides some examples of inappropriate use of compressed air and suggests alternative methods. Especially the low-pressure uses (EREE, 2004) of compressed air should be looked at carefully. Depending on the application and specific context, compressed air can be the preferred option despite its higher environmental impact:

- It can be used where other energy types cannot be used due to explosion hazard, fire risk or extreme temperatures;
- It can be executed with a high degree of cleanliness, where quality, hygiene and safety are essential;
- Pneumatic tools are often much lighter than the equivalent electrical models, making them easier for an operator to handle;
- Pneumatic tools usually wear out slower and more gradually compared to for example electric tools.

Table 19. Overview of the most common types of inappropriate use of compressed air in the Fabricated Metal Products Sector

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

Potentially inappropriate uses	*Examples within the Fabricated Metal Products sector*	*Suggested alternatives/ actions*	*Remarks*
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.

Optimization of the compressed air system configuration

The right 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 20 gives an overview of some basic considerations for the design of a performant compressed air system.

Table 20. Overview of the 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.
Stabilizing 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.

Action	*Description*
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. 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. The inlet pipe size must be large enough to prevent pressure drop and reduction of mass flow. All intake air should be adequately filtered.
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 reduce energy use for heating and save money. 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.

Optimization 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 21 gives a set of steps that can guide users to optimize their compressed air use (EERE, 2004).

Table 21. Sequence of steps that can be used to optimize 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 22 lists the main types of maintenance actions (EERE, 2004).

Table 22. 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. 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, 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 moisture control, excessive contamination, and unsafe working environments. Some very handy templates for maintenance

Action	Description
	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

Compressed air is used in various processes and applications. Between 10 and 30% of the energy consumption of a manufacturing plant in the Fabricated Metal Products sector can be attributed to compressed air (Energie Agentur, 2015). Compressed air is a convenient, easy and safe energy carrier for a lot of processes and applications.

For industrial tools and machines, the use phase accounts typically between 80 and 95% of the total life cycle impact. The energy consumption of these tools and machines is consequently 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. Therefore, compressed air is not always the best choice in terms of environmental impact.

Depending on the application and specific context, compressed air can be the preferred choice despite its higher environmental impact, because

- It can be used where other energy types cannot be used due to explosion hazard or fire risk;
- It can be executed with a high degree of cleanliness, where quality, hygiene and safety are essential;
- Air tools are often much lighter than the equivalent electrical models, making them easier for an operator to handle (website LCA2Go).

Table 19 gives and overview of some possible inappropriate uses of compressed air.

An electrically powered angle grinder typically uses about 540 to 900 W. by using a compressed air-powered equivalent the consumption will be about 3.5 kW. In this example, compressed air is not useful and should be eliminated if possible (Stanley Assembly Technologies, 2001).

Not only the selection of another energy carrier, but also the optimization 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 23).

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 23 and Figure 35 give some indications and examples of the potential savings related to optimized use of compressed air.

Table 23. 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.
Optimization of the usage regime of compressed air systems	Even when idling, compressors can consume between 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.
Optimized 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.

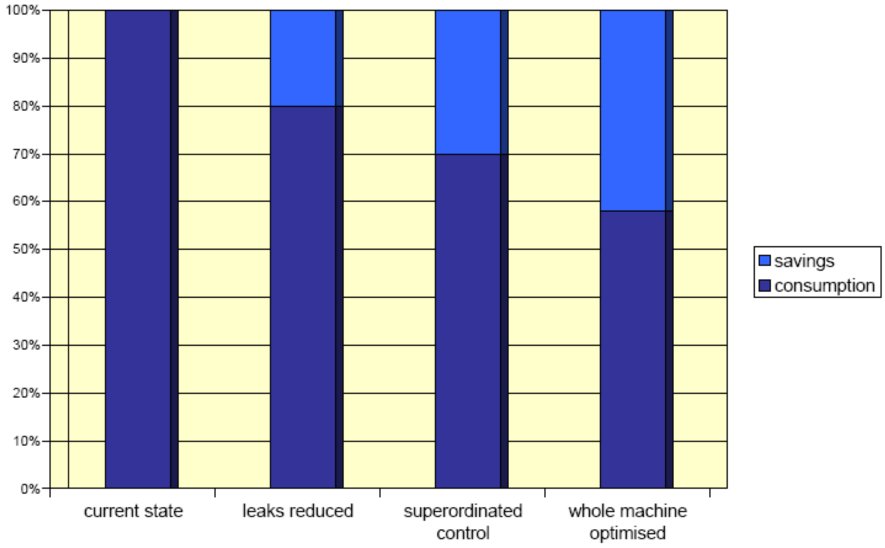

Figure 35: Potential saving related to compressed air (Ceati, 2007)

Appropriate environmental indicators

The energy consumption during the use phase is a predominant factor in the total life cycle environmental impact of tools and machines, accounting for typically 80% and more. The energy use per output is consequently a good indicator of the overall environmental performance of tools and machines. Depending on the specific context, this can be expressed in terms of kWh/kg, kWh per number of produced parts, etc. This indicator can be used for tools and machines using whatever energy carrier (compressed air, electric) (Marshall, 2013). More easy to measure is the installed power for compressed air.

For compressed air tools and machines, the conversion factor can be calculated relating the used flow of compressed air with the total electricity consumption needed to power the compressors.

To follow up the environmental performance of the compressed air tools and machines specifically (and monitor their efficiency and operational performance), an additional set of indicators can be used. These are rather of a technical nature, but give a good insight of the environmental performance of the compressed air system. These indicators include:

- Pressure of the compressed air system(s) in bar;
- Compressed air production equipment power consumption (per system) in kWh, per day, per month, per year, etc.
- Compressed air flow (per system, division, etc.) in standard cubic meter per minute.

Cross-media effects

The measures related to optimization 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 pneumatic tools using batteries, this can lead to high battery and WEEE waste streams. In case they are replaced by tools using electricity this will not give an negative impact.
As explained above, the improved energy efficiency in the utilization of the tools and machines usually outweigh these impacts.

Operational data

In the Fabricated Metal Products sector a wide range of compressed air tools and machines is used, and this in a wide variety of processes, circumstances, requirements, etc. On the other hand, this BEMP describes a broad set of measures and actions on different levels:

- Elimination of inappropriate use of compressed air;
- Optimization of the compressed air system configuration;
- Optimization of the compressed air use;
- Appropriate maintenance for compressed air systems.

That makes it impossible to describe exhaustively the operational data of all these measures. In the first instance, it is very important that companies start to measure and monitor the important parameters and indicators related to the use of compressed air, on the level of their plant, division, compressor, compressor system, machine or type of machine, etc. This helps to build up knowledge and insight in the actual performance of the compressed air system, the effectiveness of measures, the procedures, the behaviour of users, etc. Combine this with a sustained attention for the performance of the compressed air system, it becomes possible to follow up and improve its performance and to implement this BEMP.

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).

Applicability

The design (configuration), operation and maintenance of compressed air systems can be optimized in every Fabricated Metal Products company. Of course, the energy saving potential depends largely on the plant specificity and its current situation. The optimized configuration and use of compressed air systems requires some specific knowledge. Ideally, the compressed air use is followed up by an employee with the necessary skills. Of course, activities related to the design and maintenance can also be outsourced to the equipment supplier or a maintenance company.

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. These changes may be easier to implement at tipping points like replacement of old equipment, plant extensions or modifications, etc.

Driving force for implementation

The environmental performance of compressed air systems, tools and machines in the sector is largely dominated by their energy consumption, 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.

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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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2.2.10. Reduction of standby energy of metal working machines

Description

The energy consumption during standby modes often represents a significant share of the total energy demand of manufacturing processes (Duflou et al, 2011). Coolant circulation, compressed air, auxiliary components such as electronics and fans consume up to 30% of the energy use during standby (Kellens et al, 2013). These processes are required to insure machine readiness, data transfers and to avoid long warm up periods (see Table 24)**Error! Reference source not found.**. During standby mode, the machine does not produce value and thus the amount of used energy can be reduced as much as possible.

Table 24. Overview of auxiliary processes during standby mode (Duflou et al., 2011)

	Component	Function
Spindle Drives	Main Spindle Motor	Besides rotary motion, holds as well as centres work piece
	Rotary Tool Spindle Motor	Rotary motion for cutting tool
Servo Drives	*i*-Axis Motor	Linear motion for cutting tool towards *i*-axis
	Tailstock Spindle	Besides rotary motion, holds as well as centres work piece 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 System	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 visualization of program
	Lightning	Lightning the working area
	Fan	Air flow generation for cooling electrical components
Periphery System	Coolant Pump Motor	Rotary motion for pump to supply coolant circuit with pressure
	Chip Conveyer Motor	Rotary motion for chip conveyer
	Tool Change Arm Motor	Rotary motion for tool change

As energy represents power consumption over a certain time period, the standby energy can be reduced by lowering the standby power demand, as well as limiting the duration of standby activities. While the first can be obtained by selectively switching

off non-required subunits, the latter can be achieved by optimized production planning. Examples can be found in increasing the machine tool utilization, as well as (temporary) switching off non-required machine tools.

For each machine individually, a guidance list should be built indicating which components/functions need to be turned off at which specific moments. Afterwards, this can be programmed in a CNC controller accordingly. Some questions that need to be addressed are: What components to switch of after for an hour of inactivity? What component for a night/shift of inactivity? For a week-end? etc. The CNC controller can give an indication to the operator to switch off components or the latter can be done automatically.

A good example can be seen in **Error! Reference source not found.**, where in the CNC controller functions are built in to allow the machine operators to shut down non-essential function and/or to automatically active them before the shift starts. This insures the operator to start working with a warm machine, without leaving the machine using unnecessary energy during the night/weekend.

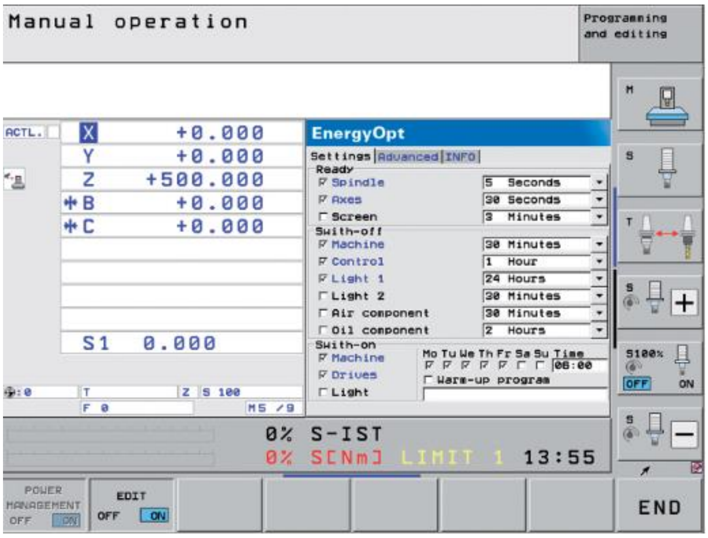

Figure 36: Energy management in a CNC controller (Heidenhain, 2010)

Achieved environmental benefits

A large reduction of energy consumption can be achieved by shutting down non-essential functions during standby of a machine. In addition, pumps, electrical servo engines and other electrical components which remain active during standby are subject to wear and aging. Selectively shutting them down can therefore greatly increase their lifetime, reduce maintenance cost and lower the amount of spare parts needed in stock.

Appropriate environmental indicators

An appropriate environmental indicator is the amount of energy used per produced unit (kWh machine power per batch).

Cross media effects

In many electrical equipment the energy peak during start up is rather large and can cause aging than in the case where machines are turn off. The latter results in higher power needs and/or early part replacement. In particular the circuit boards used for the NC controllers are vulnerable for peak loads. In addition, EDM generators and laser sources also suffer from cyclic loads, resulting in the common practice to not shut down production machines between jobs unless longer downtimes are expected.

However, consistent switch-off of auxiliary components (hydraulics, spindle cooling) or the compressed-air supply can also have the opposite effect. If the sudden removal of waste heat from auxiliary components or of the temperature-stabilizing effect of media causes thermal displacement in the machine frame, it can result in scrap 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).

Operational data

Metal working machines, such as lathes, milling machines, EDM and/or hybrid processes all consume a large amount of energy during their machining processes. Figure 37**Error! Reference source not found.** depicts the energy consumed by a rough and finishing milling operation of a rectangular aluminium housing.

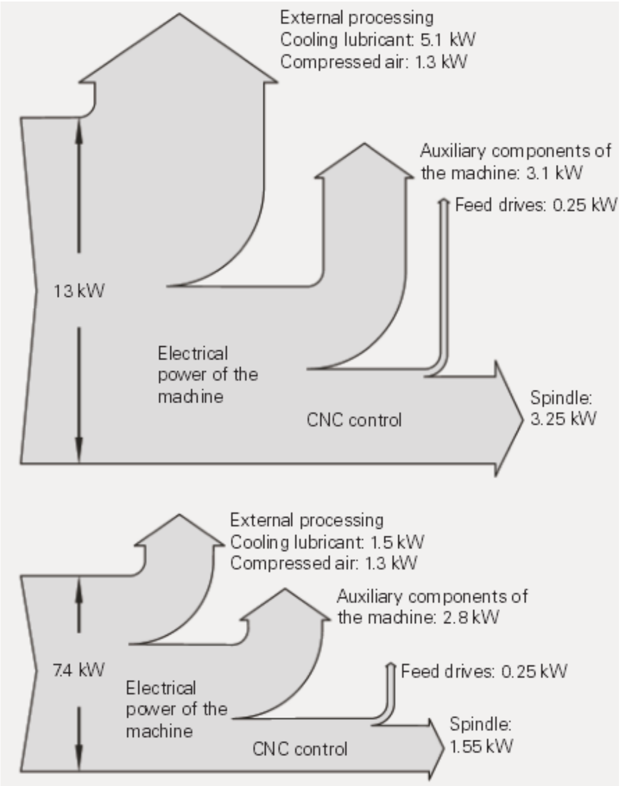

Figure 37: Power requirement for roughing (top) and finishing (bottom) milling of the housing (Heidenhain, 2010)

As can be seen the external processes, such as cooling fluid and compressed air take up a large part of the power requirement, while auxiliary components of the machine and spindle follow. The power use during production (green bar in Figure 38 left side) is scarcely higher than during standby (blue bar in Figure 38**Error! Reference source not found.** left side). The consumption of compressed air and lubricants are mostly automatically shut down or minimized when the machine is in between operations, the auxiliary components general remain active. These auxiliary components consist of the CNC system, lights, axis cooling systems and electronics.

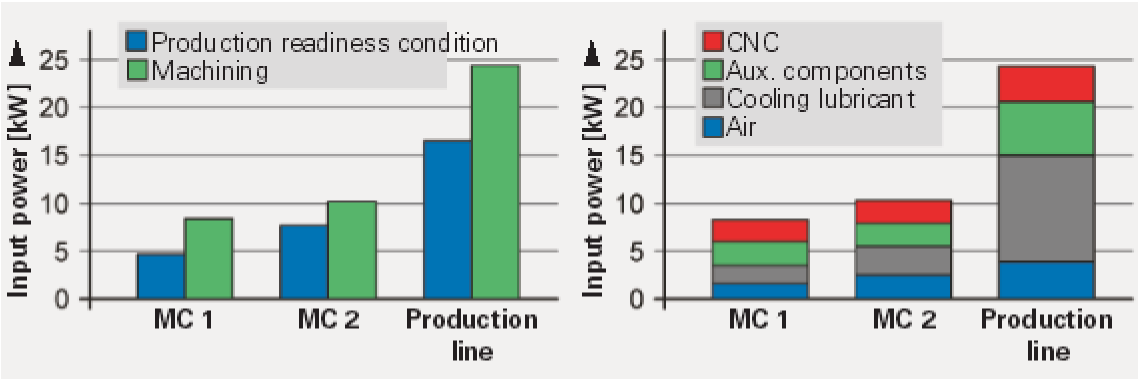

Figure 38: Machine power requirement

Kellens et al. (2013) show that for a CO_2 cutting laser the standby energy can be reduced considerably by introducing power saving modules in the controller (Figure 39)**Error! Reference source not found.**. These achieved energy savings de-activate the non-essential subunits and insure quick reactivation when the machine needs to operate, resulting in a reduction up to 66% of standby power requirement. Fanuc (the producer of the equipment) has implemented these savings on their latest controllers, allowing operators and engineers to optimize energy use without hindering production.

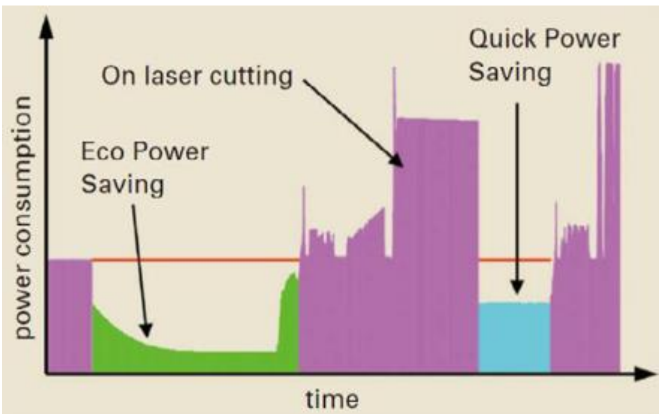

Figure 39: Energy profile for a CO_2 laser (Kellens et al. 2013)

Therefore machine operators can greatly reduce the overall machine power consumption by selectively shutting down non-essential machine activities when they work on standby mode.

Applicability

The technique is applicable in all up to date CNC controlled machine. The use of controlling software can be updated with suitable routines (programs) having the above mentioned setting possibilities.

In older machines, without the software control options, manual interventions have to be made in the hardware, which is often undesirable due to lack of flexibility and the added cost (usually the settings are lost and thus extra time is needed).

Table 25. Energy savings for several machines, comparison standby and shut down (Kellens et al., 2013)

	Studer S40	Studer S120	Colchester A50	MS NL2000MC/500	MS Dura Vertical 5100	DMU 60P
Peak power (kW)	9	6	4	9	2.4	9
Time to power-off (s)	15	10	10	15	10	15
Energy to power-off (kWh)	0.012	0.004	0.001	0.005	0.002	0.025
Fixed Power (kW)	3.69	1.69	1.16	1.58	1.02	5.45
Time to standby (s)	250	110	30	150	110	100
Energy to standby (kWh)	0.256	0.036	0.004	0.038	0.021	0.096
Total Energy Cost for Temporary Switch Off (kWh)	0.268	0.040	0.005	0.043	0.023	0.121
Energy Saving if machine idle for 30min (kWh)	1.577	0.805	0.575	0.747	0.487	2.604

In Table 33**Error! Reference source not found.** a comparison is made between either shutting down a machine, and having it reside in standby mode. The cost for shutting down and staying idle for 30 min are compared and it can be seen that for certain machines (Struder S40 and DMU 60P) idling has a significant impact on the energy consumption. Based upon these calculations, a correct shut down procedure can be developed, allowing rapid responses to production demands and improved energy use.

Economics

Figure 37**Error! Reference source not found.** illustrates machine standby power requirements, which range from 5 to 15 kW. Depending on the working regime (24h/24h or only day shift) the benefits can be significant if only a reduction of 2 to 3 kW is achieved, considering an electricity cost of 50-60 euro MWh (estimate based on average industrial end user power price, 2014). In addition, the lower rate of aging of equipment significantly lowers the amount of maintenance interventions required, driving down cost of ownership considerably.

Driving force for implementation

The driving force for implementation is the cost of energy and spare parts.

Reference organisations

Volvo Cars - productions of cars and trucks.

In their production plan in Ghent, they shorten the stand-by time of hydraulic groups (Volvo, 2012)

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2.3. Best environmental management practices for the manufacturing processes

The proposed BEMPs for the manufacturing processes are split up in BEMPs for all manufacturing processes:

- 2.3.1 Application of solid low-friction coatings on tools and components;
- 2.3.2 Application of wear- and corrosion-resistant coatings of tools and equipment;
- 2.3.3 Selection of coolant as environmental and performance criterion

BEMPs for forming processes:

- 2.3.4 Incremental Sheet metal Forming (ISF) as alternative for mould making;
- 2.3.5 Additive manufacturing of complex equipment - flow optimization for optimal heat transfer and temperature control;
- 2.3.6 Multi-directional forging: a resource efficient metal forming alternative.

BEMPs for removing processes:

- 2.3.7 Hybrid machining as a method to reduce energy consumption
- 2.3.8 Machining of near-net-shape feedstock.

and BEMPs for finishing processes:

- 2.3.9 Reduce the energy for paint booth HVAC with predictive control;
- 2.3.10 Selection and optimization of thermal processes for curing wet-chemical coatings on metal products.

2.3.1. Application of solid low-friction coatings on tools and components

Description

In the Fabricated Metal Products sector lubricants are widely used for a variety of applications, e.g. for reducing friction, protecting them against wear and keeping moving surfaces clean and cool. Lubricants have to be replaced and disposed of after a certain time. In order to avoid, or if not feasible, lower the use of liquid lubricants, solid low-friction coatings can be applied. These solid low-friction coatings will lower wear and make it possible to lubricate closed or unreachable (space) systems for extended time. The advantages and disadvantages of applying solid low-friction coatings are listed in Table 26.

Table 26. Advantages and disadvantages of applying solid low-friction coatings

Advantages	*Disadvantages*
- Are highly stable in high-temperature, cryogenic, vacuum and high-pressure environments	- Have higher coefficients of friction and wear than for hydrodynamic lubrication
- Have high heat dissipation with high thermally conductive lubricants, such as diamond films	- Have poor heat dissipation with low thermally conductive lubricants, such as polymer-based films
- Have high resistance to deterioration in high-radiation environments	- Have poor self-healing properties so that a broken solid film tends to shorten the useful life of the lubricant
- Have high resistance to abrasion in high-dust environments	- May have undesirable colour, such as with graphite and carbon nanotubes
- Have high resistance to deterioration in reactive environments	
- Are more effective than fluid lubricants at intermittent loading, high loads, and high speeds	
- Enable equipment to be lighter and simpler because lubrication distribution systems and seals are not required	
- Offer a distinct advantage in locations where access for servicing is difficult	
- Can provide translucent or transparent coatings, such as diamond and diamond-like carbon films, where desirable	

A whole range of solid lubricant films are listed below:

- Nanotubes, nano-onions, and other nanoparticles (C, BN, MoS_2, and WS_2);
- Nanocomposite coatings (WC/C, MoS_2/C, WS_2/C, TiC/C, and nanodiamond);
- Diamond and diamond-like carbon coatings (diamond, hydrogenated carbon (a-C:H), amorphous carbon (a-C), carbon nitride (C_3N_4), and boron nitride (BN) films);
- Superhard or hard coatings (VC, B_4C, Al_2O_3, SiC, Si_3O_4, TiC, TiN, TiCN, AlN, and BN);
- Lamellar film (MoS_2 and graphite);
- Non-metallic film (titanium dioxide, calcium fluoride, glasses, lead oxide, zinc oxide, and tin oxide);
- Soft metallic film (lead, gold, silver, indium, copper, and zinc);
- Self-lubricating composites (nanotubes, polymer, metal-lamellar solid, carbon, graphite, ceramic, and cermets);
- Lamellar carbon compound film (fluorinated graphite and graphite fluoride);
- Carbon;
- Polymers (PTFE, nylon, and polyethylene);
- Ceramics and cermets.

Figure 40 illustrates comparison of different solid lubricants in friction coefficient and lifetime.

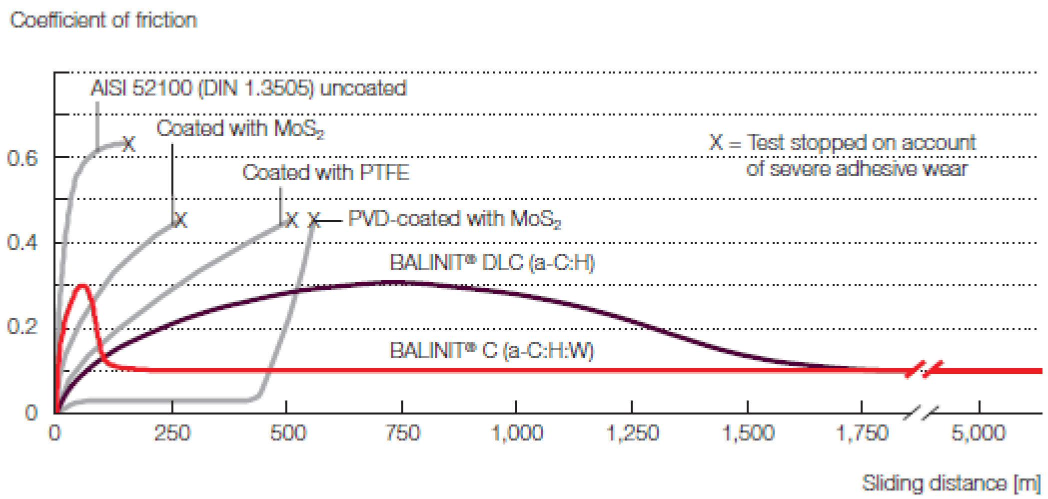

Figure 40. Comparison of frictional performance; BALINIT is a solid low-friction coating (Oerlikon Balzers, 2010)

Figure 41 presents a comparison of the life time for a lab test with different types of lubrication. Important to note is that depending on the type of contact and the type of load, different systems of solid lubricants can be the most beneficial. An example is the comparison between MoS_2 and DLC (Diamond Like Carbon). In particular, MoS_2 friction degrades in humid atmosphere, but is excellent in vacuum or low humidity, while for DLC, the opposite is true. Some of the solid lubricant coatings have a temperature limit or cannot be used in certain processes like food or medical, because of toxicity). Figure 41 illustrates that coating (dry use) can increase the number of cycle times with a factor 100.

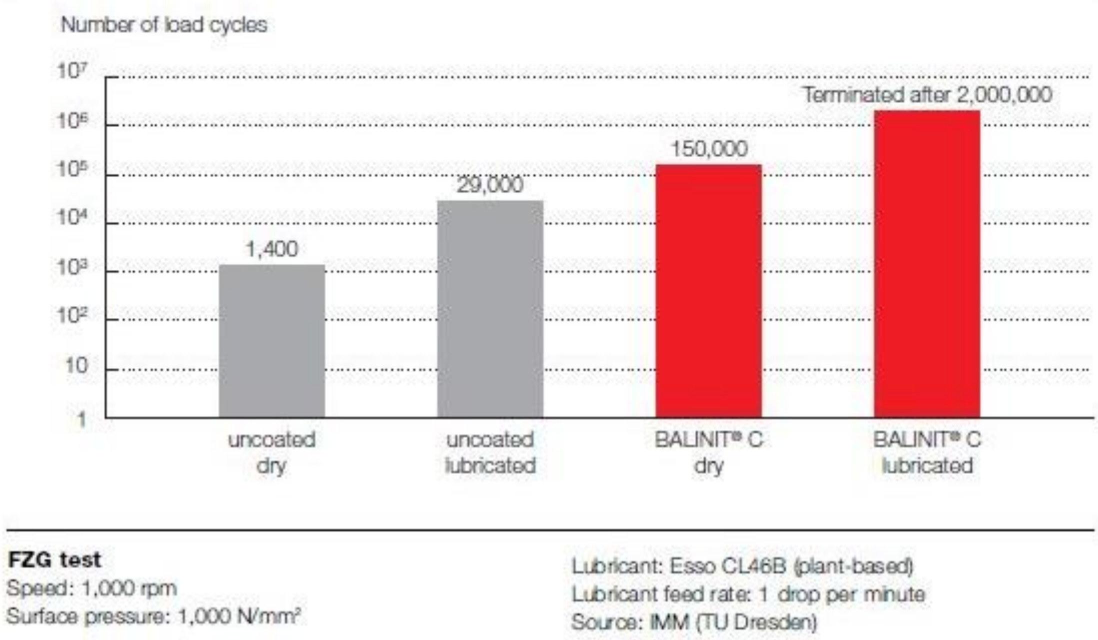

Figure 41. Solid low-friction coating (BALINIT C) in dry running and starved lubrication (gear test) (Oerlikon Balzers, 2010)

The techniques to apply the solid low-friction coatings, depending on the application, are i. vacuum technology like PVD and CVD, ii. (thermal) spraying and iii. flow coating.

Achieved environmental benefits

The application of solid low-friction coatings leads to limited or no use of liquid lubricants, resulting in lower disposal of lubricants. The induced higher life time of tools and equipment leads to less scrap production and less material use to make new products.

More optimal processes and energy use can be achieved as well, e.g. faster processing, more consistent process speed and less interruption.
Furthermore, the application of solid low-friction coatings requires no liquid grease so operators are no longer exposed to (toxic) additives, VOCs, etc., resulting in healthier and cleaner work environment.

Appropriate environmental indicators

Appropriate environmental indicators are listed below:

- Amount of waste linked to the lubricants use: kg waste for disposal per year; kg waste for recycling per year. Figure 41 shows that a coating can increase the number of load cycles by a factor 4. (drops of lubricant/produced part);
- Amount of scrap production (number of waste products or kg of burr/production run or time magnitude);
- Increased productivity (number of produced parts/tool).

Cross-media effects

An important cross-media effect is that solid low-friction coatings can have poor heat dissipation with low thermally conductive lubricants, such as polymer-based films. Therefore, it is important to know the main function of the coating and lubricant for a given application.

The application of solid low-friction coatings requires additional technologies and techniques, which represent an additional energy use.
As illustrated in Figure 41 coatings do not prevent the use of lubricants. The lubricant, in combination with a coating, can further increase the number of cycle times. Doing so offsets a large number of the benefits related to the elimination of lubricants. The largest environmental benefits are obtained if no lubricant is used.

Limited literature is available on the toxicological effects of these coatings. As they have a high resistance, the amount of materials sets free during the use will be low.

Operational data

Because there is no vapour present between lattice plates, MoS_2 is effective in high-vacuum conditions, under which conditions graphite will not work. The particle size and film thickness are important parameters that should matched with the surface roughness of the lubricated component. Particle size selection is much important for rough cut surfaces, such as hobbed open gears, than for highly finished surfaces, such as those found on bearings. Improperly matched particle sizes may result in excessive wear by abrasion caused by impurities in the MoS_2.

The temperature limitation of MoS_2 at 400°C (752°F) is imposed by oxidation. MoS_2 oxidizes slowly at atmospheres up to 600°F. In a dry, oxygen-free atmosphere it can function as a lubricant up to 1300°F. The oxidation products of MoS_2 are molybdenum trioxide (MoO_3) and sulphur dioxide. MoS_3 is hydroscopic and causes many of the friction problems in standard atmosphere. MoO_3 is a preferred form of the metal used as an additive for various other metals, which is its primary use.

The issue of where MoS_2 should be used, versus graphite or tungsten disulphide, is generally best addressed by a lubrication engineer. For most commercial applications, these are relatively simple choices. In aerospace applications where unique environments and exotic materials are employed, these questions often take substantial research to provide the best answers (Climax Molybdenum Company, 2015). The low friction coefficients of MoS_2 often exceed that of graphite (Machinery Lubrication, 2015).

Applicability

Almost all metallic products or tools can be coated with a certain type of solid low-friction coating. The technique is mostly used for turning, moving pieces in tools and equipment. Applications include piston skirts, bearings, splines, slides, shafts, plungers, gears, etc.
Due to the existence of different application techniques all product dimensions going from small up to very large products can be coated (only limited by the specific limits

of the coating equipment). Since the coating technique is an additional technology, every company can, at any time, start to incorporate solid lubricant coatings in their products or processes. Due to the existence of job coating companies, even the investment of coating technology and knowledge is not necessary. Job coating gives the opportunity to subcontract the application of the coating with no impact on existing production within the manufacture site.

Certain production parameters need adaptation to get the highest performance with the coated products. In fact, a portfolio of different solid low-friction coatings at different companies depending on the specific application or use exists or it is compiled by the sector companies in order to have a guidance on which coating technology is suitable. Nevertheless it can be difficult sometimes to find the right coating for a certain application. Experts can support companies in the selection of the most suitable coating solution.

Economics

Solid low-friction coatings can improve process conditions, give and added value to a product and increase the life time of the products.

It makes the use of lubricated surfaces possible in processes where liquid lubricants are not possible (food and medical processes (e.g. medication production) or dust environments), which makes it a cost-effective solution.

Driving force for implementation

The main driving forces for applying solid low-friction coatings are:

- Less downtime for tool replacement;
- Faster throughput time;
- Cost savings on new tools;
- Less scrap production;
- Added value products;
- Coatings readily available and mature deposition techniques with job coating facilities.

Reference organizations

Oerlikon Balzers: Oerlikon Balzers develops coatings and coating processes, markets systems and production equipment, contract coating services in a global network are provided.
http://www.oerlikonbalzerscoating.com/buk/eng/

CSEM: CSEM founded in 1984, is a private applied research and development centre specializing in micro- and nanotechnology, systems engineering, photovoltaics, microelectronics, and communications technologies.
http://www.csem.ch

Dow Corning: http://www.dowcorning.com

Sirris Smart Coating Application Lab: The Smart Coating Application Lab offers support to technological companies that want to innovate their products with functional coatings.
http://www.smartcoating.be

Reference literature

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http://www.climaxmolybdenum.com/, last accessed on 28th September 2015.

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2.3.2. Application of wear- and corrosion-resistant coatings of tools and equipment

Description

In the Fabricated Metal Products sector wear-resistant coatings are applied to increase the lifetime of products and components. Typical applications for wear-resistant coatings are punching, forming, machining and moulding in manufacturing of products. Techniques to apply wear-resistant coatings are mostly PVD (Physical Vapour Deposition), CVD (Chemical Vapour Deposition), plating, laser cladding, welding or thermal spraying and all their variations. The coatings applied are mostly much harder than the underlying bulk material, increasing the wear-resistance. Coating thickness is in the range of a few µm for PVD up to mm in case of cladding and welding. Some coating processes, e.g. welding and spraying, are mobile which means that a (re)application of a wear-resistant coating can be performed on site for large tools and machine components/equipment.
There exists a large portfolio of different wear-resistant coatings depending on the specific application or use. However, it can be difficult sometimes to find the right coating for a certain application[37].

Corrosion-resistant coatings, sometimes combined with the functionality of wear-resistance, protect the underlying material from corrosive elements. Corrosion processes not only influence the chemical properties of a metal, but also generate changes in its physical properties and its mechanical behaviour. Corrosion leads to direct costs for replacing damaged material and components and indirect costs, such as loss of production, environmental impacts, transportation disruptions, injuries, and fatalities.

The corrosion-resistant coatings are metallic, organic or inorganic. A wide variety of corrosion-resistant coatings are available to match the performance requirements of a specific application, e.g. resin/lubricant blend offering corrosion protection, a fluoropolymer, ferrous metal coating for anti-galling and minor corrosion resistance, high gloss topcoat for epoxy and inorganic zinc, abrasion-resistant coating that protects by binding ceramic particles to a resin system, etc.
The techniques for applying the coatings can be used in the own machinery of the Fabricated Metal Products companies (Table 27). In case the company produces/manufactures tools and equipment for other industries, these practices can be applied as well.

The coating application is an additional process, which any company from the sector can incorporate at any time at their processes and/or products. Due to the existence of companies which offer coating services for tools and equipment for companies from

[37] TiN, CrN, TiC, CrC, TiAlN, AlTiN are all thin wear-resistant coatings but the performance of the different coatings depends on the application (temperature, speed, load, counter material)

the sector, the investment of coating technology and knowledge might not be necessary.

Table 27. Application of surface treatment processes (Oerlikon Blazers, 2010)

	Protection against scuffing	*Protection against abrasion*	*Protection against corrosion*	*Application areas*
Electroplated hard chrome	+	++	+	Chemical apparatus, food industry, hydraulics
Electroless nickel plating	+	+	+++	Chemical apparatus, food industry, hydraulics
Diffusion processes (nitriding, nitrocarburisation, boronising)	+	++	+	Engine components, tools
Plasma spraying	+	++	++	Turbine vanes
CVD (thermal)	++	++	+	Tools
PVD hard coatings (TiN, TiCN, TiAN, CrN)	++	++	+	Tools, machinery, engine components, motor sport
PVD/PACVD carbon coatings (WC/C, DLC)	+++	++	++	Machinery, engine components, motor sport

Achieved environmental benefits

Wear- and corrosion-resistant coatings can lead to a more efficient and a reduction of resource use, i.e. use of new materials for making new products.
Furthermore, due to the extended lifetime, there will be a reduced manufacturing of new products to replace the worn products with all environmental issues involved (carbon emissions, energy consumption, etc.).

PVD and CVD depositions take place in a vacuum chamber making it a very clean, ecological, healthy process compared to other techniques.

Appropriate environmental indicators

Appropriate environmental indicators are

- Extended lifetime of tools (number of processed parts/tool);
- Decrease in materials for new tools (number of tools /production batch);
- Higher quality production (less non-conformal parts/ production run);
- Less cooling/lubricating fluids (litres/production run).

Cross-media effects

The aim of wear- and corrosion-resistant coatings is to extend the lifetime of tools and equipment by using, in many cases, rare materials. Therefore an overall analysis of the lifetime is needed, to avoid the reverse effect.

The different coating technologies differ largely in energy consumption for applying the coating, e.g. plating requires less energy than PVD. On the other hand the emissions related to the processes differ as well, e.g. plating produces significant waste streams, while PVD has almost no emissions. However, the environmental impact of applying a coating to reduce wear and corrosion remains limited compared with the environmental impact of not applying a coating.

Operational data

Sandvik (2008) indicates that the application of a coating has significant beneficial effects on the overall cost. Figure 42 shows the sources of cost in a typical machined part. Because machine and labour costs are so high, higher productivity and efficiency offer the best chance for significant savings. Table 28 shows that increased productivity by using high quality tools, e.g. treated with wear- or corrosion-resistant coatings, offers more potential in cost reduction than a 30% discount on the tool cost itself.

Table 29 gives some examples of wear-resistance coatings on moulds and the longer lifetimes for those moulds.

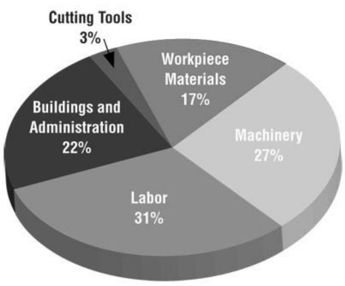

Figure 42. Machining cost and impact of a 20% increased cutting speed with high quality tools (Sandvik, 2008)

Table 28. Machining cost and impact of a 20% increased cutting speed with high quality tools (Sandvik, 2008)

In euros	*Today*	*30% discount*	*20% increase cutting speed*
Variable Costs			
Cutting tools	.30	.21	.45
Workpiece materials	1.70	1.70	1.70
Fixed Costs			
Machinery	2.70	2.70	2.16
Labour	3.10	3.10	2.48
Building & admin.	2.20	2.20	1.76
Cost Per Part	€ 10.00	€ 9.91	€ 8.55
Savings		**1%**	**15%**

Table 29. Examples of longer mould lifetime by using wear resistance coatings for the production of synthetic materials (FME CWM, 2005)

	synthetic material	*not coated*	*coated*	
		number of injections	coated material	number of injections
mould (1.2379) screw	POM	500,000	PVD TiN	> 3,000,000
chrome plated mould	Phenol	3 months (24h / day)	Ion implantation	4 times longer up to unlimited
mould in steel	glass polyester	31,000	Ion implantation	684,000
mould in steel	phenol	100,000	PVD TiN	1,000,000

The application of coatings will lead to an increased productivity (less downtime) and decrease in throughput time.

Applicability

Almost all metallic and ceramic products or tools can be coated with a certain type of wear- or corrosion-resistant product ranging from small products like cutting knifes to very large heavy duty equipment like moulds, dyes, etc.

Correct selection of the coating type in function of the main requirement or application, i.e. corrosion and/or wear, is of high importance. Coating can be used for food and medical approved applications, where the coating requirements are more stringent. The environmental impact assessments in such cases require a more in

depth analysis taking the full product life cycle (and risks) into consideration (Benveniste, 2008).

Certain production parameters need adaptation to get the highest performance with the coated products, e.g. coated cutting tools might require changed cutting process parameters. Employees need to be aware that products have a coating. Pre-treatment of the tool during production might need an adaptation period. In some companies, moulds are sandblasted prior to production or in-between to clean the surface. When a coating is applied, such a sandblasting pre-treatment could damage the coating.

Economics

The cost associated with the application of a coating is in most cases low compared to the great advantages of lifetime extension of tools and equipment. Sandvik (2008) indicates that the overall benefits of an application with a coating are higher than the cost savings of buying an uncoated tool (cost of an new uncoated tools is 30% lower than of a coated tool).

Furthermore, subcontracting the application of the wear- or corrosion-resistant coatings has advantages that there is no impact on the existing production in the company and often leads to efficient resource expenditure.

Driving force for implementation

The main driving forces for implementing wear- or corrosion resistant coatings in the Fabricated Metal Products sector are:

- Less downtime for tool replacement;
- Faster throughput time;
- Cost savings on new tools/equipment;
- Less scrap production;
- Higher quality products;
- Added value products.

Reference organizations

Tata Steel Europe. Tata Steel Europe provides different steel products with wear-resistant coatings. Examples of their products are: boom arms, powered roof supports, chassis and base plates, safety-related structures.
http://www.tatasteeleurope.com/en/products-and-services/long/plate/high-strength/high-strength

Ionbond. Ionbond provides highest performance PVD, CVD and PACVD wear protection, low friction and decorative coatings as well as coating equipment. www.ionbond.com

Kanigen Group. Specializing in electroless surface treatment of technical products, Kanigen Group offers several versions of electroless nickel, using the Kanigen® process. This process gives the plated parts interesting new mechanical and chemical properties. http://www.kanigen.eu

Oerlikon Balzers. Oerlikon Balzers develops coatings and coating processes, markets systems and production equipment; contract coating services are available. http://www.oerlikonbalzerscoating.com/buk/eng/

Plasmajet Advanced Coatings. Plasmajet specialises in wear resistant surface treatment. For over40 years Plasmajet has been developing technical coatings for all sorts of applications. http://www.plasmajet.be

Sirris Smart Coating Application Lab. The Smart Coating Application Lab offers support to technological companies that want to innovate their products with functional coatings. http://www.smartcoating.be

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Schmitt G., 2009, Global Needs for Knowledge Dissemination, Research, and Development in Materials Deterioration and Corrosion Control, white paper, the world corrosion organization.

2.3.3. Selection of coolant as environmental and performance criterion

Description

The main aim of coolants or cutting fluids in general is to avoid overheating of machinery/tools and to lubricate the cutting surface to facilitate cutting and avoid local welding. In the 1980's the cost of coolant acquisition, circulation and disposal was around 3% of the total part cost, while nowadays it reaches up to 16% (Kauppinen, 2002; DGUV, 2010, **Error! Reference source not found.**). More complex cooling systems, increased price for purchasing and disposal of coolant and more demanding machinery tasks are the reasons for the increased cost. The increased cost results in a moving trend from wet machining to dry machining.
Furthermore bad cooling techniques reduce the lifetime of machinery considerably.

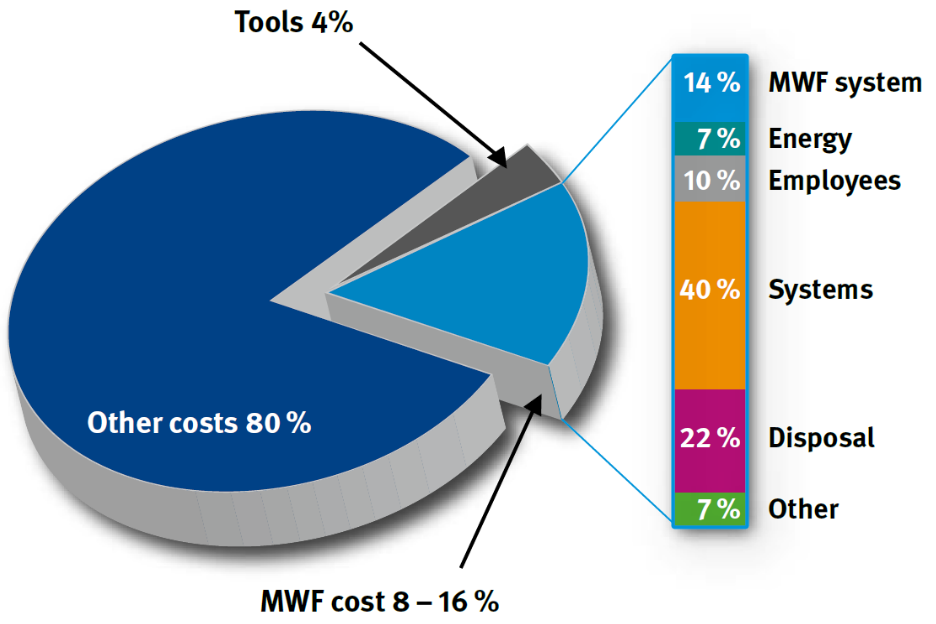

Figure 43. Metal working fluid (MWF) costs in metal machining (DGUV, 2010)

There are two main trends in eco-efficient cooling in machining operations:
- Cryogenic cooling;
- Minimum Quantity Lubrication.

Cryogenic Cooling

Compared to typical coolants (oil or emulsion), cryogenic cooling solutions (with liquid CO_2 and a temperature of approximately -80°C or with N_2 and a temperature of approximately -196°C) offer the most promising results. Due to their strong cooling capacity, the positive effect on tool wear, part quality and machining speed is big. Therefore, cryogenic solutions (**Error! Reference source not found.**) have a high impact on resource use. Companies that use cryogenic cooling increase their productivity (**Error! Reference source not found.**) and reduce the use of energy and others consumables considerably.

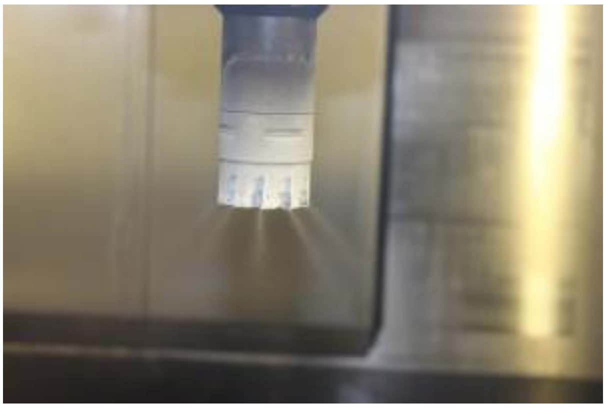

Figure 44. Cryogenic cooling solution on milling tool (Composite machining, 2014)

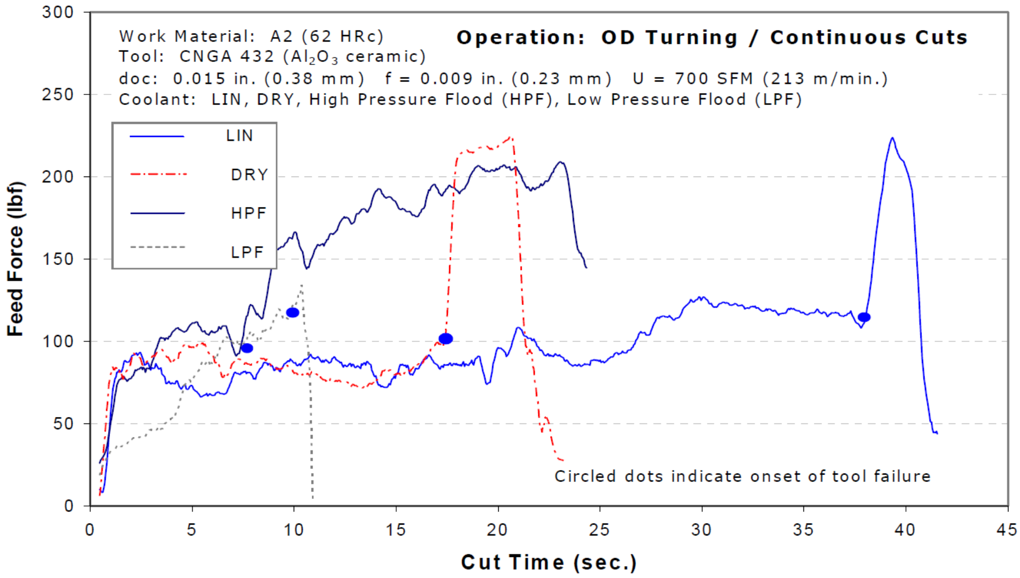

Figure 45. Tool lifetime in turning with Liquid Nitrogen Coolant (LIN) compared to Dry and Regular Cooling (AMT, 2015)

Minimum Quantity Lubrication (MQL)

MQL is a technique with pulsed oil in pressed air using less lubricoolant compared to wet techniques (**Error! Reference source not found.**). There are less thermal shocks and the cooling is very consistent compared to traditional cooling systems. This results in a longer lifetime of machinery/tools and increased cutting speeds. The cooling is also more focused on the cutting point and there is no spreading of oil at the machine. The surface quality is often better and the cooling costs are lower.

MQL is driven by tool and coating design. Development in tool material and coatings allow machining with less cooling. MQL fits well together with new coatings and this allows a more environment-friendly process.

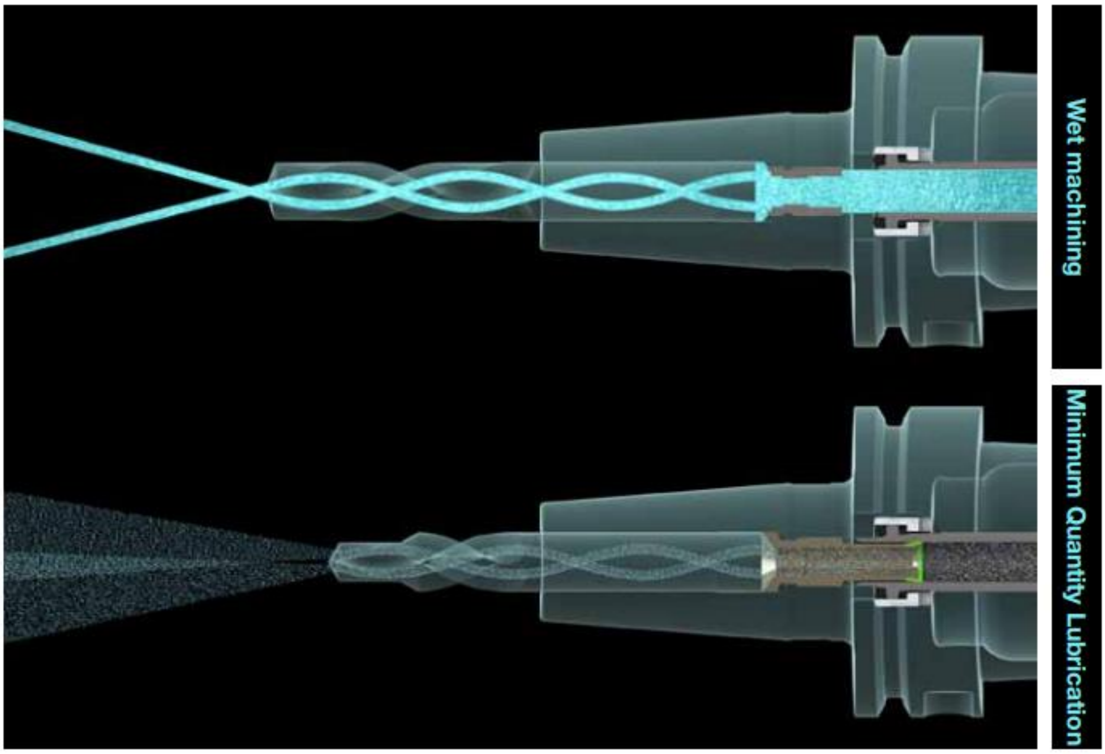

Figure 46. Wet and MQL cooling (Guhring, 2013)

Achieved environmental benefits

The application of cryogenic cooling can, depending on the workpiece material, significantly decrease throughput rate (due to increased machining efficiency) and therefore also the energy consumption per produced part. Next to this, the longer tool life decreases the amount of required tools and avoids excessive waste.

An important advantage of cryogenic cooling is the fact that CO_2 and N_2 can evaporate and solve in the air, without any harmful impact on the operator. These benefits are very important compared to the oils and emulsions which are difficult to recycle, and which cause harmful emissions.

Appropriate environmental indicators

Appropriate environmental indicators are:

- Emissions of oil emulsions to air and water (l emulsion/machine hour);
- CO_2-emissions to air, due to lower energy use (kWh/production batch);
- Longer lifetime of machinery / tools (number of tools per production batch).

Cross-media effects

The production and storage of liquid CO_2 or N_2 result in energy use. The CO_2 used is a by-product of the chemical industry (e.g. production of ethylene, Messer, 2015). The CO_2 of the chemical process is liquefied in the chemical plant (instead of discharged to the air) and sold to the Fabricated Metal Products industry.

Figure 47**Error! Reference source not found.** gives an idea of the material, infrastructure and energy flows for both technologies: Conventional cooling and cryogenic cooling.

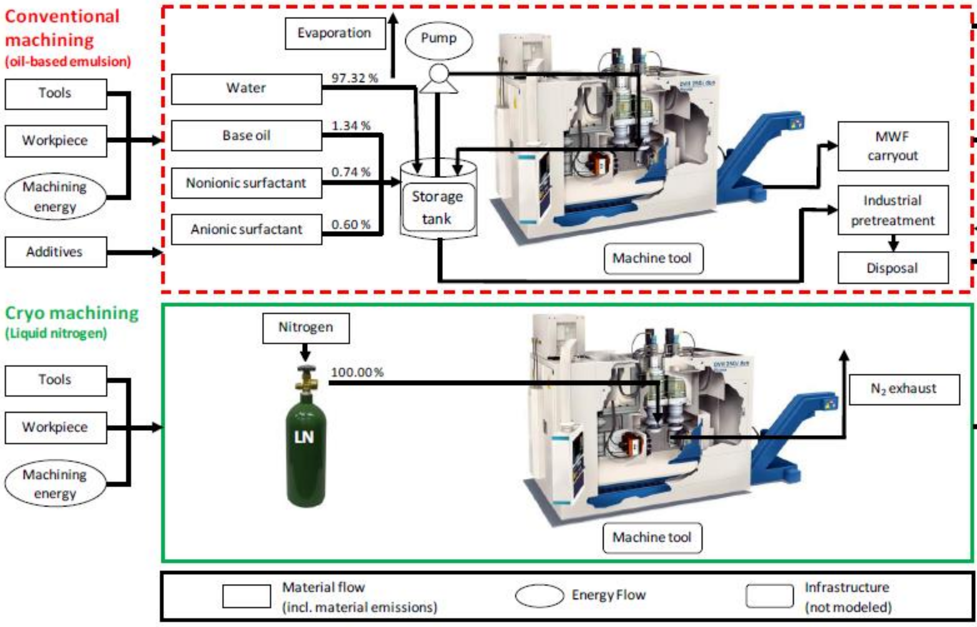

Figure 47. Comparison of flows in conventional and cryogenic machining (Pušavec and Kopač, 2011)

Table 30. Comparison of the LCA of emulsion and cryogenic cooling (Pušavec and Kopač, 2011)**Error! Reference source not found.** gives an overview of the LCA of both machining emulsions and liquid nitrogen as cooling fluid. Conventional emulsions contain approximately 1.5% mineral oil, 97% water and 1.5% surfactants. Liquid N_2 causes less waste at each level, except that it needs cooling water during the "freezing process".

Table 30. Comparison of the LCA of emulsion and cryogenic cooling (Pušavec and Kopač, 2011)

Category	Unites	Mineral oil	Anionic surfactant	Nonionic surfactant	Liquid nitrogen
Energy use	MJ	5.94	60.20	51.50	1.80
Global warming potential (GWP)	kg CO_2eq	3.56	3.00	5.60	0.00
Water use	kg	0.00	6.00	0.00	*50.00
Acidification	g SO_2eq	3.83	25.00	15.80	0.00
Solid waste	g	5.19	64.20	27.10	0.00
Land use	m^2	0.00	0.00	0.00	0.00

* cooling water at 15°C

During a sub-zero cooling of the tool, it is possible that there are side effects in the product material. The work piece is also "frozen", and this is not always allowed.

Operational data

It is important that operators use the optimal cutting conditions. The cooling must be chosen taking into account the material type, the coating and the tools.

Case study – Inconel – (SI)– cryogenic cooling

At the University of Slovenia (Pušavec et al, 2009, 2011), a case-study involved a comparison between conventional and cryogenic cooling of Inconel. The total sum of production costs (including machining cost Cm, tool cost Ct, electricity cost Ce, cooling lubrication fluid cost Cclf and cleaning cost Ccl) was made. Figure 48**Error! Reference source not found.** shows the differences between the two.

The case study showed that at a low cutting speed (and productivity), conventional cooling is cheaper. At high cutting speed (and productivity), cryogenic cooling becomes more interesting.

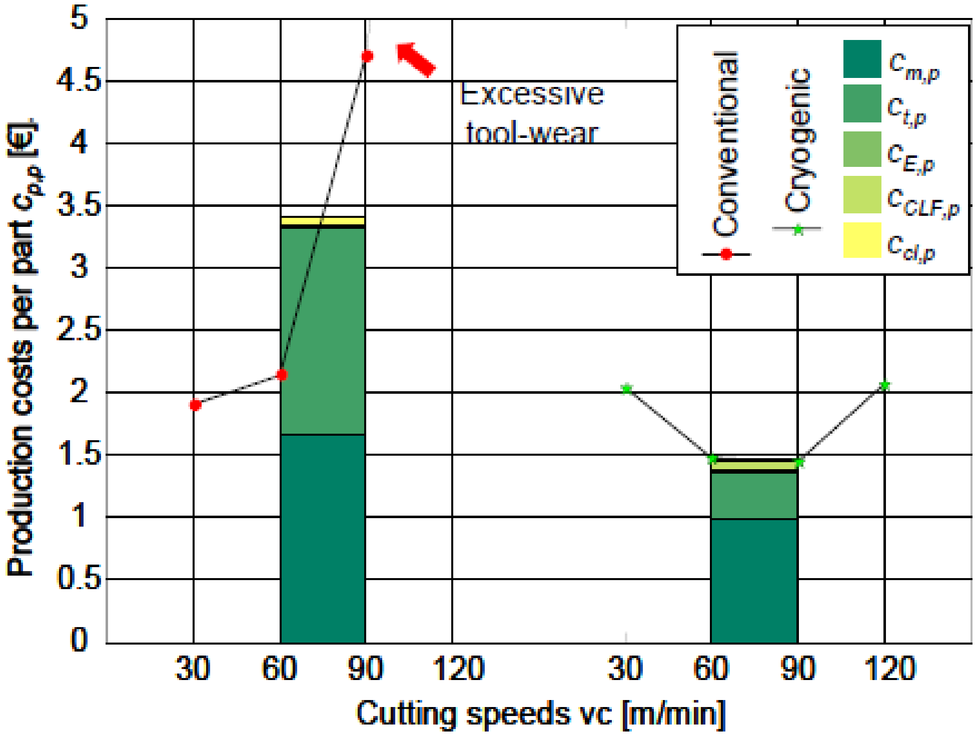

Figure 48. Comparison of cost per part (Pušavec and Kopač, 2011)

This kind of comparisons differs of course from case to case (for each material/tool/cutting condition-combination).

MQL

Lubricant is supplied by means of a minimum quantity lubrication system (MQL system). Application of a targeted supply of lubricant directly at the point of use lubricates the contact surfaces between tool, work piece and chip. The lubricant is either applied from outside as an aerosol using compressed air or it is "shot" at the tool in the form of droplets.

Another possibility is internal lubricant feed through the rotating machine tool spindle and the inner channels of the tool. Figure 49**Error! Reference source not found.** shows the basic differences between external and internal feed.

Table 31**Error! Reference source not found.** gives an overview of the advantages and disadvantages of both methods.

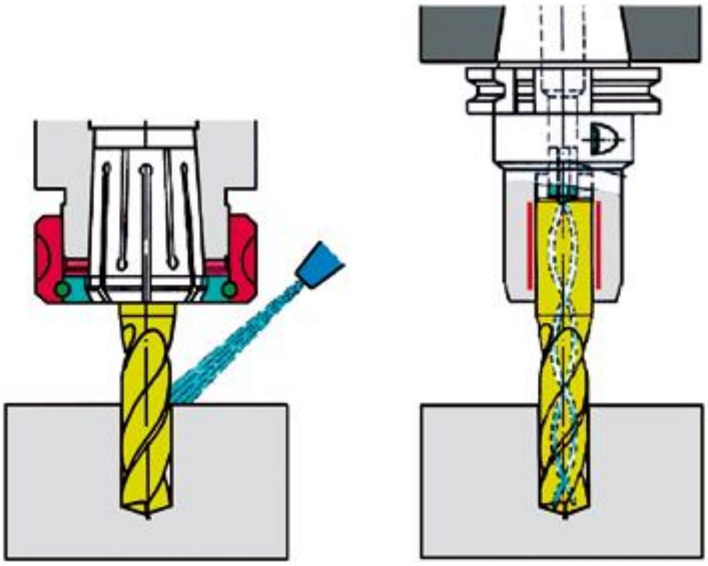

Figure 49. External and internal lubrication feed (DGUV, 2010)

Table 31. Advantages and disadvantages of external and internal feed of MQL (DGUV, 2010)

External feed	
Advantages	**Disadvantages**
• Simple adaptation • Low investment costs • Little work required to retrofit conventional machine tools • Rapid response characteristics • No special tools required	• Limited adjustment options for the nozzles due to different tool lengths and diameters • Possible shadowing effects of the spray jet when machining • Possible shadowing effects of the spray jet when machining
Internal feed	
Advantages	**Disadvantages**
• Optimal lubrication at the cutting point (for each tool, even for inaccessible points) • No scattering or spray losses (see external feed) • Optimised lubricant quantity for each tool	• Special tools required • High investment costs • Suitability of the machine is required

Applicability

Cryogenic cooling can be used for milling of hardened metals (and composite materials) with ceramic tools and turning.

MQL can be installed for all materials, but sometimes there is a need for a better cooling capacity. For hard machining MQL is very interesting, but when thermal

aspects are very crucial other cooling types such as oil/emulsion have better (cooling) capacities and are sometimes necessary. Table 32**Error! Reference source not found.** and Table 33**Error! Reference source not found.** give an overview of the different areas where MQL can be used. External feed can be used for retrofit of conventional machines.

Table 32. Areas of application for minimum quantity lubrication and dry processing (DGUV, 2010)

Material / Process	Aluminium		Steel		Cast
	Cast alloy	Forged alloy	High-alloy steels, rolling bearing steel	Free-cutting steel, quenched and tempered steel	GG20 – GGG70
Drilling	MQL	MQL	MQL	Dry	Dry
Reaming	MQL	MQL	MQL	MQL	MQL
Thread cutting	MQL	MQL	MQL	MQL	MQL
Thread rolling	MQL	MQL	MQL	MQL	MQL
Deep drilling	MQL	MQL		MQL	MQL
Milling	Dry	MQL	Dry	Dry	Dry
Turning	MQL/dry	MQL/dry	Dry	Dry	Dry
Hobbing			Dry	Dry	Dry
Sawing	MQL	MQL	MQL	MQL	MQL
Broaching			MQL	MQL/dry	Dry

Table 33. Examples of areas of minimum quantity lubrication application with production processes and motivation (DGUV, 2010)

Sector	Work pieces	Material	Processes	Motivation
Automotive suppliers	Throttle housings	GD-AlSi12Cu4	Milling, Drilling, Reaming	Reduction of component costs by 8 %
Printing machine manufacturers	Drilled and tapped strips	Ck45	Milling, Drilling, Threading, Reaming	Shortening the process time: 10.49 min ‹ 7.32 min
Automotive manufacturers	Gears Car gearboxes	Case-hardening steel 20MoCr4	Shaping	Environmental protection Reduction of component costs by approx. 5 %
Electronic components	Connector elements, ‹ 1 cm^3	Brass	Drilling, Milling	High drag-out of cutting oils
Pneumatic cylinders	Connector	Al die cast GD-ZnAl4Cu1	Tapping and grooving	Pollution of the machine environment, metalworking fluid cost savings, less maintenance and cleaning work, higher cutting values
Tool and die construction	Tools	Tool steels	Milling and turning	80 % reduction of maintenance and cleaning work, better surface quality, shorter processing times
Aviation	Aircraft integral components	Al forged alloy	Milling	Environmental protection Pollution of the machine environment, low procurement costs of machines
Power plant manufacturers	Turbine blades	X22CrMoV 12.1, CrNi steels	Milling	Flood lubrication unreliable, tool life tripled

Economics

The main economic advantage of cryogenic and MQL cooling is a reduction in machining times, which will on its turn, result in a reduction in lead times (up to 60%). Next to this, the longer lifetime of tools (up to 3 times) and the increased quality of parts will greatly reduce costs as well (5ME, 2015).

Care should be taken to avoid excessive use of cryogenic coolant due to its large cost (around 100 euro/tonne for CO_2).

For MQL, the initial tooling costs are a little bit higher but the overall process is much cheaper as shown in **Error! Reference source not found.**

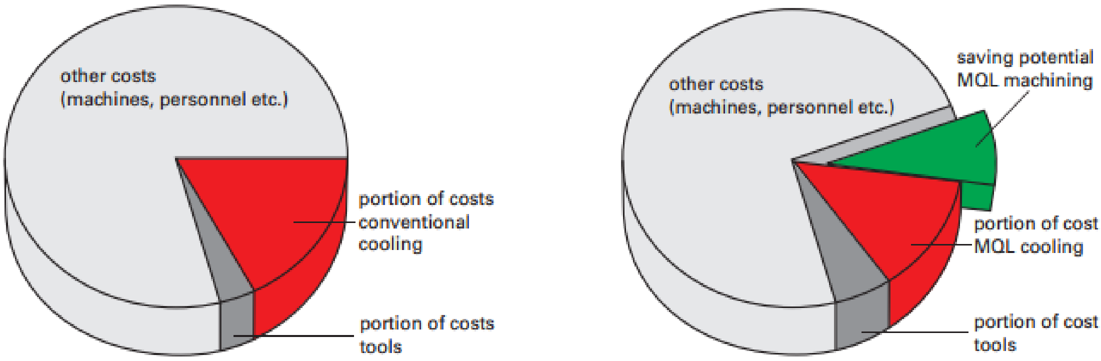

Figure 50. Saving potential for MQL (Guhring, 2013)

Cooling consumption can be reduced by a factor 30 for the same productivity and quality. Costs are halved in comparison to standard (oil/emulsion) cooling. This has a large impact on the environment (Ward, 2013). The productivity can be increased with 20%.

Driving force for implementation

Import driving forces for implementation are:

- Cost saving;
- Higher productivity;
- Higher quality;
- Reducing oil emission;
- Human health.

Reference organizations

Ford: MQL uses an extremely small amount of oil versus conventional wet-machining. For a typical production line of 450,000 vehicles, MQL can save 282,000 gallons of water per year (Ford, 2013).

5ME (US): provider of cryogenic machining equipment. http://www.okuma.com/5me

Audi (Hungaria Motor Kft.) Audi Hungaria Motor Kft. in Györ is one of the most important suppliers of engines for Audi and the Volkswagen Group and is EMAS certified. The use the MQL technology (EU, 2015).

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2.3.4. Incremental Sheet metal Forming (ISF) as alternative for mould making

Description

In the metal fabrication 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 of energy is needed to mill and a lot of material finally ends up as waste. 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 might offer a solution to some of the problems linked with the classical processes, i.e. incremental sheet metal forming (ISF). 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 forming 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).

SF 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 forms the sheet toward a desired geometry by a proper trajectory on the sheet itself (Figure 51). 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. These advantages took the researchers studying ISF to the conclusion that this technology is a suitable alternative to traditional stamping when small lots of high differentiated products have to be manufactured (Ingarao et al., 2012).

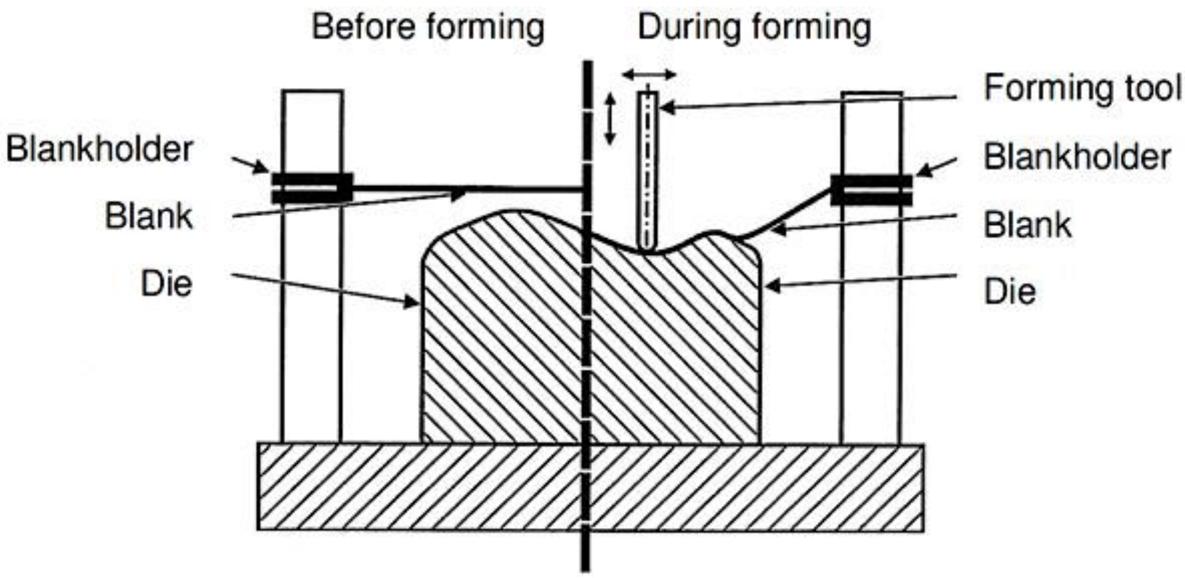

Figure 51. Process principle of incremental sheet forming, ISF (ISF-Light, 2012)

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 forming 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. RTM moulds. Since the only forming process is a contouring operation, the processing time for making such moulds is significantly less than milling a block of metal, thus reducing energy consumption and raw material.

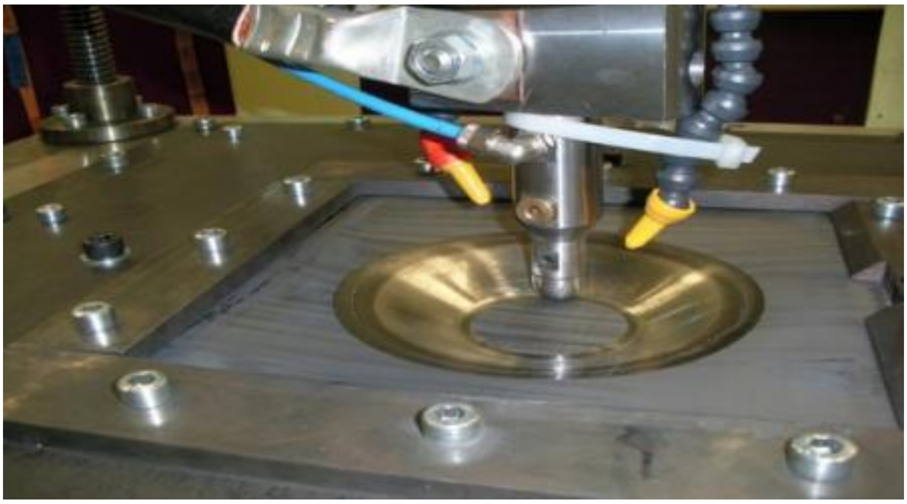

Figure 52. Incremental sheet metal forming installation (INMA, 2014)

Configurable (modular) setups are possible, both in size and tooling (Figure 3).

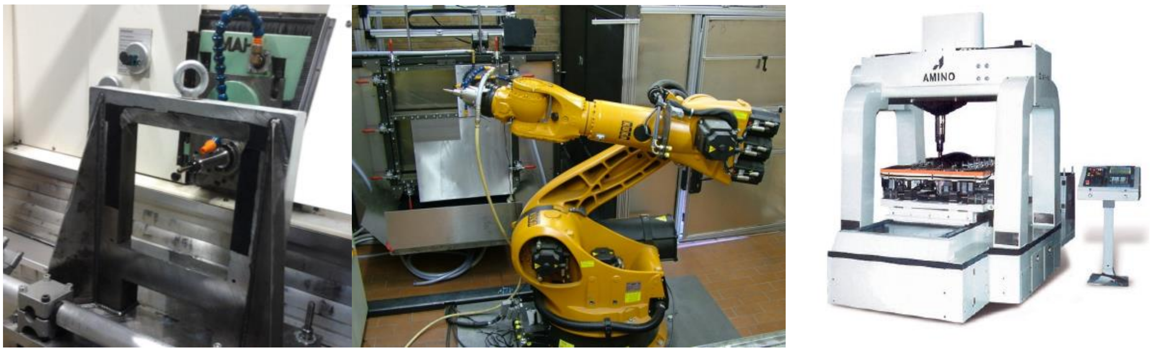

Figure 53. Platforms used for ISF, from left to right: CNC milling machine, industrial robot, dedicated machine (Aminio, 2015)

Achieved environmental benefits

The major environmental benefits are the reduction of raw material and energy use for the applications for which ISF is the optimal choice. The reduction of energy use is achieved due to a shorter production time (only contouring operation). 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) indicates 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 consumption 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/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) presents an exergy analysis of ISF processes and compares two ISF variants (single and double sided) to conventional forming and hydro forming processes. The study indicates that, from environmental perspective, ISF is

advantageous for prototyping and small production runs up to 300 parts (Kellens, 2013).

Appropriate environmental indicators

Appropriate environmental indicators are:

- Reduction of material use:
  Comparison of case studies on material consumption between classical process on mould manufacturing (milling, eroding, etc.) and ISF (deformation of 'thin' sheet) and the required material quality/alloy/properties.
    - This comparison can be either a full LCA or a simplified LCA based on semi-quantitative analysis – Y/N.
    - Other indicators are, kg material per mould.
- Reduction of energy use:
  Comparison of case studies on energy consumption between classical process on mould manufacturing and ISF. A possible indicator could be kWh/mould, kWh/product made in this mould.

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 x2,000mm and even larger. The following platforms can be used, i.e. milling machine, industrial robot, dedicated machine (Figure 53). Plate thickness typically varies between 0.5 mm and 2-3 mm.

The manufacturing of parts with ISF requires a case by case approach, considering material properties, features, existing manufacturing capabilities, batch size, post processing, etc. Considering the relatively low industrial adoption of this merging technology Fabricated Metal Products companies often choose to be supported by competent centres for implementation of this technology.

Applicability

ISF can be used for a wide variety of materials and product geometries. 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 54).

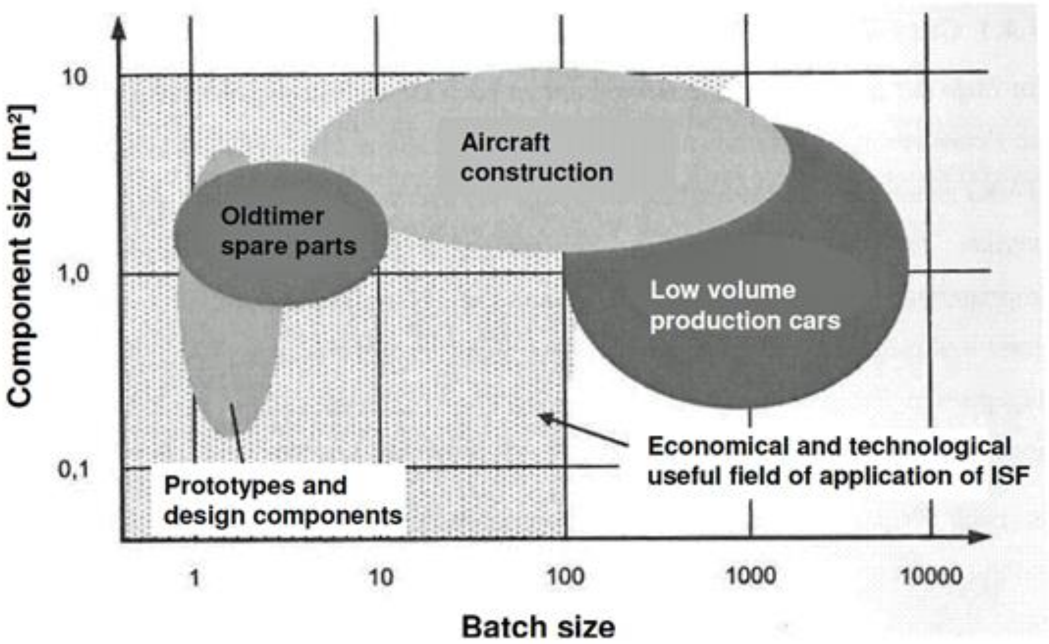

Figure 54. Current and potential fields of application of incremental sheet forming (Ames, 2008)

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 55.

Figure 55. 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.

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).
Table 34 makes a cost comparison between deep drawn product versus two ISF processes.

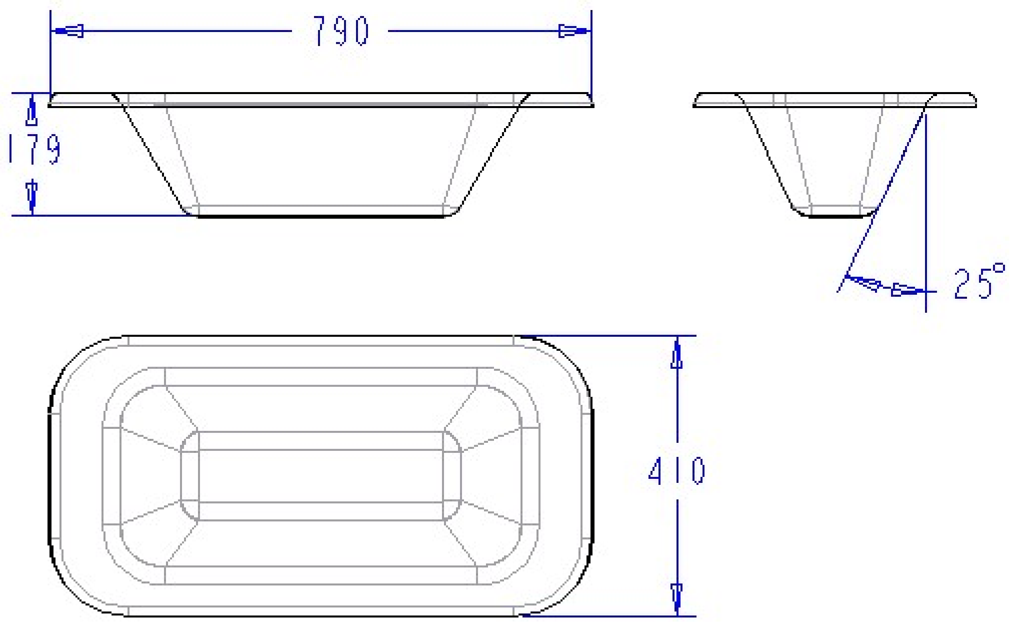

Figure 56. Dimensions of the piece used in this economical calculation (Lamminen et al, 2003)

Cost of setting up and NC programming is € 50 in both cases. Cost of deep drawing dies is estimated at € 12,800.

Table 34. 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 forming path 1,465 m	horizontal forming speed 30 m/min, vertical feed 0.5 mm per step, total length of forming path 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 57 shows a diagram of the cost for incremental forming and deep drawing as a function of the production volumes.

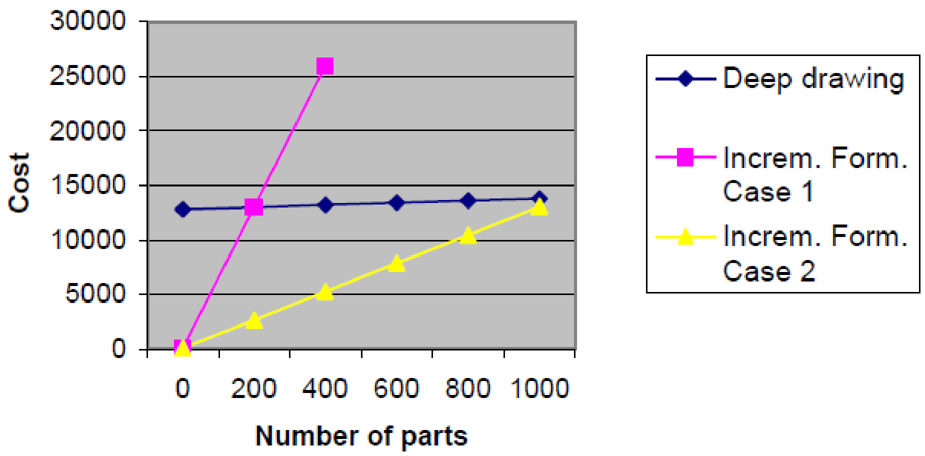

Figure 57. Cost comparison diagram for incremental forming and deep drawing

It should be noted that 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 should not 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).

Reference organizations

Beauvary (DE): Beauvary's activities focus on small-batch sheet metal manufacturing for automotive and non-automotive.
http://www.beauvary.com/index.php

Ford 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/.

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2.3.5. Additive manufacturing of complex equipment - flow optimization for optimal heat transfer and temperature control

Description

Additive Manufacturing (AM) is a term to describe the technologies for building 3D objects by adding a material, layer by layer, e.g. metal or plastic. Common to AM technologies is the use of a computer, 3D modelling software (CAD), machine equipment and layering material. Once a CAD-sketch is produced, the AM equipment reads in the data from the CAD-file and lays down or adds successive layers of liquid, powder, sheet material or other, in a layer-upon-layer fashion to fabricate a 3D object. The term AM encompasses many technologies, including subsets like 3D Printing, Rapid Prototyping, Direct Digital Manufacturing, layered manufacturing and additive fabrication (Figure 58, AMazing, 2015).

AM is already used to make some niche items, such as medical implants, and to produce plastic prototypes for engineers and designers. But the production of more complex items, such as heat exchangers or critical metal-alloy parts to be used in jet engines, remains small scale. Although 3D printing for consumers and small entrepreneurs has received much publicity, the technology could have the highest commercial impact in manufacturing processes (MIT Technology Review, 2013).

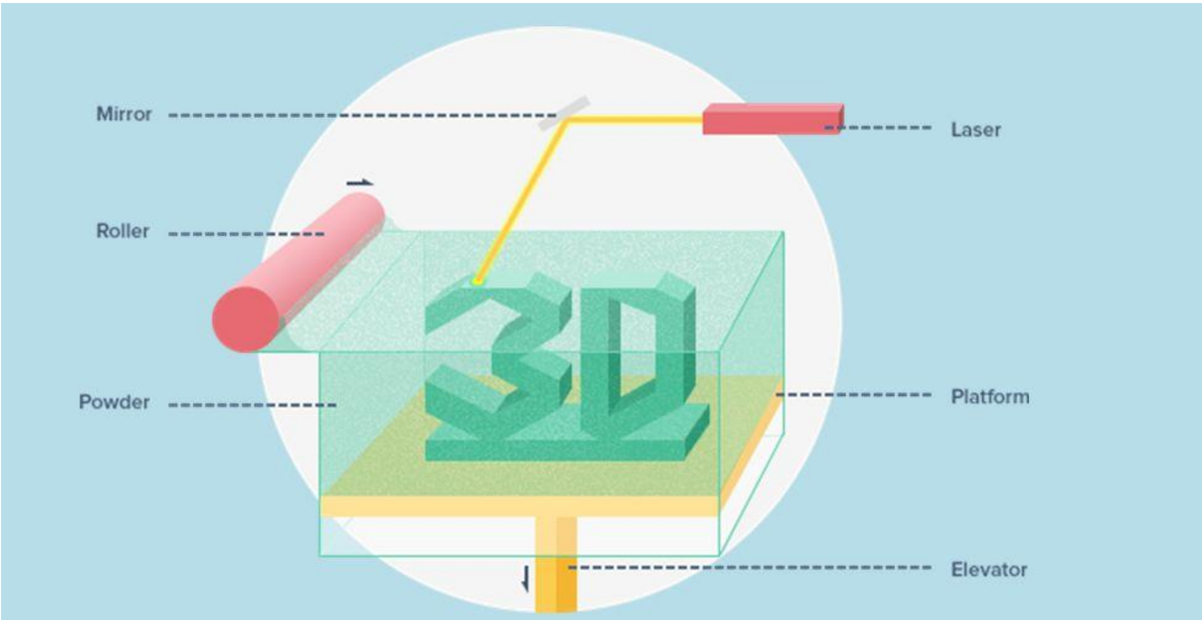

Figure 58: Schematic view of layer by layer build up in additive manufacturing process

An application in the metal fabrication sector, where AM can lead to significant benefits, is flow optimization for optimal heat transfer and temperature control. A heat exchanger is such a typical piece of equipment built for efficient 'heat transfer' from one medium to another. The media may be separated by a solid wall to prevent mixing or they may be in direct contact (Sadik & Hongtan, 2002). Due to restrictions in classical productions methods, the construction of these devices is often not

optimal. With the new opportunities that AM offers it is possible to create new geometries that are impossible to manufacture in one piece with conventional technologies. Because products are built layer by layer, new shapes can be created. With these new shapes optimal flow paths for heat exchangers can be created, and this in a smaller volume while still having a larger surface for heat exchange. Due to the smaller volume, materials are used in a more efficient way compared to the classical production method (Figure 59).

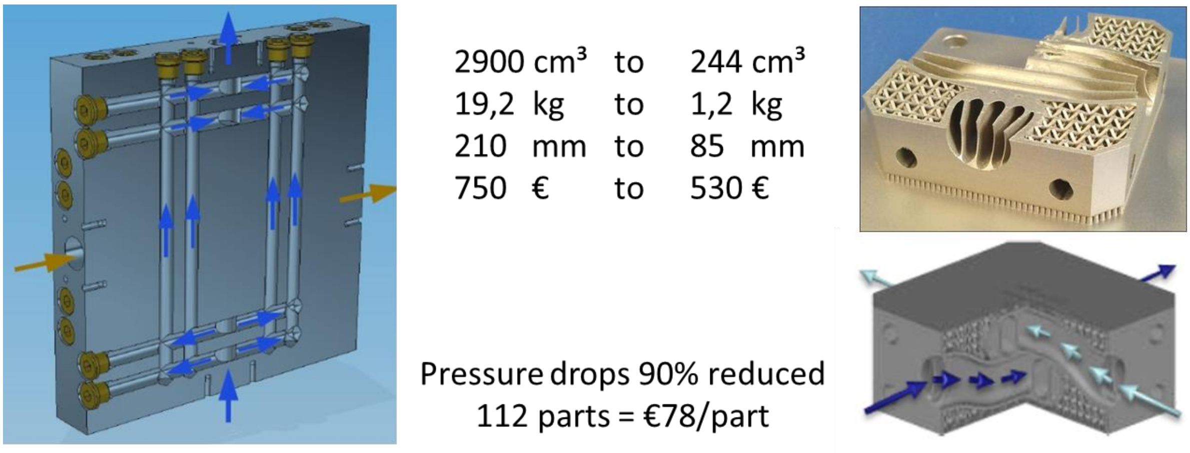

Figure 59. Hydrauvision heat exchanger 'Impossible-crossing' (Compolight, 2015)

The technology or process engineering department in a company in the Fabricated Metal Products sector can identify where the critical equipment parts are situated and can therefore play an important role in the application of this technique.

Manufacturing complex equipment by AM requires a strategic plan to implement this new way of producing. It also requires a new way of thinking. By radically changing the design of complex equipment a close collaboration can arise between customer and supplier. This co-development needs to be supported by a high level of information exchange, which is important for the success of applying AM.

Achieved environmental benefits

The environmental benefits can be subdivided in primary and secondary effects. The primary effects cover the increased efficiency of material and energy consumption, better performing heat exchangers, longer lasting products requiring less material to provide the same or a better functionality. Weight and volume optimization of the heat exchangers, which leads to a reduced energy consumption for transportation, can be considered as secondary effects. Furthermore, the possibility AM offers to produce locally requires less transportation. The technique also leads to a better control of extreme (thermal) conditions by the heat exchangers, which reduces the wear of components. A lower risk of emission of gasses/fluids is also recognized since the complex products are made out of one piece instead of assembled parts.

A LCA study indicates that AM has a lower environmental impact than conventional machining (Serres et al., 2011). A reduction of material consumption up to 75% and CO_2 emissions to 40% have been indicated (EADS, 2013). Furthermore, AM for complex equipment can lead to a life time increase for e.g. parts requiring cooling of 2 to 3 times.

Appropriate environmental indicators

Two environmental indicators can be identified:

- Raw material use during production (amount of material (kg)/product, AM vs. traditional manufacturing in %,);
- Energy use across entire value chain (amount of energy (kWh)/ product, AM vs. traditional manufacturing in %).

Cross-media effects

When implementing AM one should take into account the Total Cost of Ownership (TCO), since the inherent cost of AM is higher compared to traditional processes. To make it economically valid, companies should consider the complete value chain of parts. From raw material, production, post processing, warehousing, transport, waste management, sales to end of life cost. AM has an impact on each of these steps in the life cycle of the part. This extended impact makes it complex and hard to make an accurate prediction of costs and benefits.

Same accounts for LCA comparisons. In today's literature (2015), many elements of the value chain are simplified or neglected. But, as mentioned above, a holistic view is needed to make a study valid. The functional unit is the key element in such studies. To define this one should regard the complete system that will be redesigned for AM. Typically, when a part is redesigned for AM, existing features are integrated, new features are added, assemblies are eliminated, etc. This changes the value of the part that is created. Besides the value of the part itself, due to the nature of producing with AM, the value of tied up capital of stock parts, the value of the time to market, the value of local- and extreme production agility and transport should be calculated as well. (but are hard to calculate)

As showed in the example of Sylvania (see below, *Layerwise, 2015*) the part itself will be more expensive to produce with AM. But, by using AM, an assembly of 20 parts becomes 1 part what makes the part more durable and more effective. This makes that the production can run more efficient and has to stop less frequent to change the burners.

Operational data

Hydrauvision is a specialist company in hydraulics. The heat exchanger design utilizes complex channels and light weigh structures ("lattices") for optimal flow and heat exchange (Figure 60). Some identified benefits of AM are a reduced pressure drop with a factor 10 lower (without post processing), an improved heat exchanging, reduced weight from 19 kg to 0.74 kg, reduced volume from 2,900 cm³ to 244 cm³ (Compolight project, 2015).

Three illustrative cases studies published by LayerWise (2015):
i. ADM realized a weight reduction of 75%. Drastic reduction of flow resistance by defining channel geometry using freeform surfaces exactly according to CAD design. The circulation properties improved with 80% (Figure 60).
ii. Form freedom allowing products that cannot be made with conventional technology. Shape complexity is not charged because cost is dependent on the weight of the part. By manufacturing a single part (instead of an assembled part made by conventional technology) the operating, installation and maintenance cost can be reduced because they need to form a hermetically connected part. Also the leakages due to assembly and fitting issues are resolved (Figure 61).
iii. Better controlled cooling process delivers higher-quality parts that do not warp and contain fewer hot spots. The cycle time of moulded plastics was reduced with 15% (Figure 62).

Figure 60. Component that connects cooling circuits

Figure 61. Burner component from for Diametal

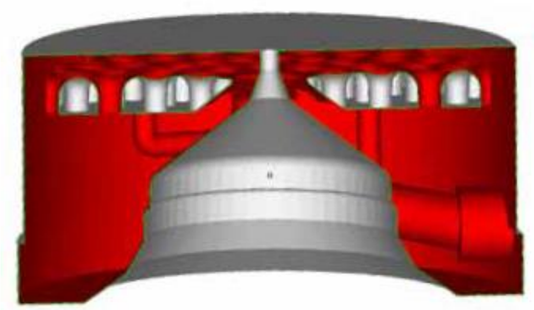

Figure 62. Injection mould insert with optimal cooling channels

Case study Havels Sylvania (UK) - gas burner (Laserwise, 2015)
A burner produced with additive manufacturing resulted in:

- 50% less burner material;
- Life time extension (triple) due to lower temperatures of burner material up to several months non-stop operation;
- Lower metal erosion on 90 degree edges resulted in an increased quality of produced parts;
- Reduced cost and down time: even with burners being ca. 20% more expensive, the burners are 60% more affordable;
- 3 times less production stops to replace the burner.


Figure 63. Left: conventional burner consisting of over 20 parts, right: new AM burner made by AM out of one single piece

Applicability

AM for flow optimization, heat transfer optimization and temperature control can be best applied in the sector in case of the following characteristics of the complex equipment/items: complex geometries, internal channels, lightweight structures, low volume parts and many connection pieces. Furthermore benefits can be achieved with AM for critical high temperature and/or high cooling requirements and applications and in case of use of high grade steel alloys (titanium, inconel, cobalt-chrome, etc.).

Economics

In general AM for flow optimization, for heat transfer optimization and temperature control leads to a better ratio of cost versus efficiency. The main (economic) advantages are situated in production cost, production time and product quality consistency, especially for small series/uncommon geometries. Hydrauvision reports for example a reduced production cost from € 750 to € 530 for a heat exchanger, mainly due to the more efficient use of materials and energy during production (Compolight project: http://compolight.dti.dk/).

The economics of AM evolve. Bigger and faster machines, new materials, integrated post processing and quality control, all enable AM to be more cost competitive. Although this evolution is significant, the price level of AM will remain higher than for traditional methods. AM should be used with care and with knowledge. The full potential of the technology should be exploited to be economically and ecologically valuable.

Driving force for implementation

The main driving forces for implementing AM of complex equipment, e.g. flow optimization for optimal heat transfer and temperature control are:

- Increased efficiency of resource use during production (materials and energy);
- An alternative for casting of complex parts requiring less raw materials;
- Reduced cost for small series;
- Increased efficiency of the equipment, e.g. optimal flow in heat exchanger;
- Low weight and small/custom-made volume solutions.

Reference organizations

Hittech Group BV. Hittech Group is a Group of centrally controlled independent companies which operates as a system supplier, extended workplace and partner of OEM companies. Demo products of heat exchanger: Hittech/Within technologies.

Companies – partners for AM of metal products:
Norsk Titanium (NTi) is a Titanium component producer based in Norway that uses its novel game changing Direct Metal Deposition (DMD)technology to produce high quality, complex Titanium components for industrial applications (http://www.norsktitanium.no/en).

Avio Aero is a GE Aviation business which designs, manufactures and maintains components and systems for civil and military aviation (http://www.avioaero.com).

LayerWise is the first production centre in Belgium that exclusively focuses on the Additive Manufacturing (AM) process for metal parts (http://www.layerwise.com).

Companies using ADM parts:
Havells Sylvania (http://www.havells-sylvania.com/): producer of lighting. Havells Sylvania produces metal pieces in lamps with the use of AM.

Diametal (http://www.diametal.be/) is producer metal parts on CNC milling and turning machines. They use AM for the production of different pieces with a complex geometry (Metalise, 2015)

Hydrauvision (http://www.hydrauvision.com/) uses AM for the production of complex heat exchanger (Dormal, 2013).

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2.3.6. Multi-directional forging: a resource efficient metal forming alternative

Description

By forging complex products with a high variation in cross-section, a significant amount of material usually ends up in burrs. In the standard forging process, material is formed by the pressure from above, so that the deformed material can "escape" to each side to form a large burr. For complex geometries, more than 40% of the material can end up in the burrs. These burrs must be removed by machining in the finishing steps (Figure 64).

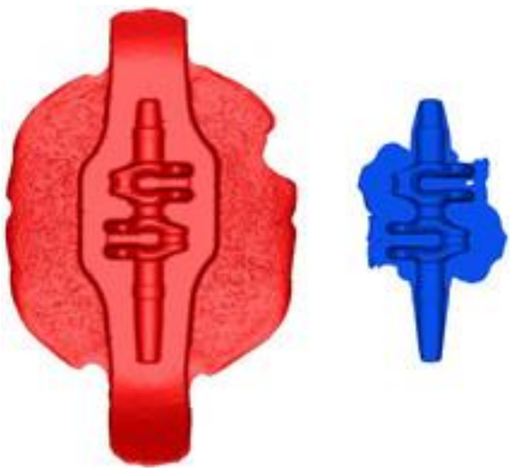

Figure 64. Significantly lower burr percentage: The multi-directionally forged crankshaft (right) compared with a conventionally forged one (IPH-Hannover, 2014)

A recently developed "burr free" and multi-directional forging concept reduces significantly the formation of burrs 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 the burr formation;
- Production of larger series (magnitude 1000s).

Some examples include crankshafts, connecting rods, worm wheels, trunnions and handles.
To implement burr free multi-directional forging, companies can take following steps:

(1) Development and simulation of the process steps

In this phase, the new forging concept, consisting of a sequence of (typically 4) forging steps, is developed. To do this successfully, a thorough knowledge of the relevant forging technologies 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 as well, using appropriate Finite Element Modelling. This

gives valuable information about the quality of the (intermediate and final) forgings 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 which machines (e.g. forging presses) will be used;
- Development of the forging tools (based on the findings of the previous step) including forging tools designs and heating concept.

(3) Validation of the process sequence and the resulting materials and component properties
In this final step before real industrial production, a test run is performed to validate the new multi-directional forging concept. Do the forgings have the required properties? Is the quality consistent and reproducible? Possibly, some minor modifications or "fine-tuning" are needed in this step.

Figure 65. Examples of components that can benefit from burr free and multidirectional forging (Hatebur, 2015)

Achieved environmental benefits
Direct effects are the reduced formation of burrs, which leads to a reduction of the material needed to produce the work piece. The actual material savings will depend on the specific material and geometry of the work piece. In the case of the two cylinder crankshaft (elaborated in the REForCH project), burr formation was reduced from 54% to 7% (which corresponds with 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 (non-hazardous) waste, and the process reduces the need of finishing machining operations.

The latter leads to a reduction in energy consumption (both related to the machining itself and the embodied energy in the burrs) 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 extra heated before this step using for example induction heating. Nevertheless this extra need of energy consumption, the total energy consumption of the forging process is about 20% lower than for the conventional forging (REForCH, 2014). This is mainly related to the reduction of the total weight of the material that must be heated before forging.
Finally, an important environmental benefit is that upstream in the value chain, less materials must be produced, which leads to a reduction of emissions and resource use.

Appropriate environmental indicators

Since multi-directional forging leads to savings of material and energy needed to manufacture a forging, the: following environmental indicators are considered appropriate:

- Percentage (%) of generated burrs per unit: this indicator describes how material efficient the process is, and can be calculated as the amount of starting (or input) material minus the net weight of the finished forging (expressed in kg). This evidently equals the amount of material that is lost in the different forging steps;
- Total energy required for the forging process, in terms of energy per piece.

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 burr free multi-directional forging consists of multiple steps: Figure 66. The multi-directional forging is typically applied at the end phase of the forging sequence (in the case of the crankshaft, in step 4 out of 5 forging operations). For the work piece, this corresponds to intermediate parts as illustrated in Figure 67.

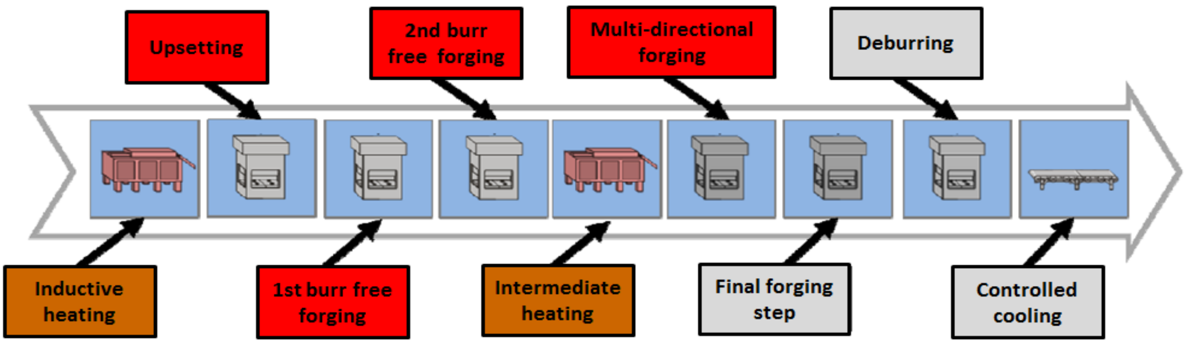

Figure 66. Example of a burr free multi-directional forging sequence of a complex steel part (e.g. crankshaft) (IPH-Hannover, 2015)

Figure 67. 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 minimize formation of burrs, 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 a burr free one as shown in Figure 68.

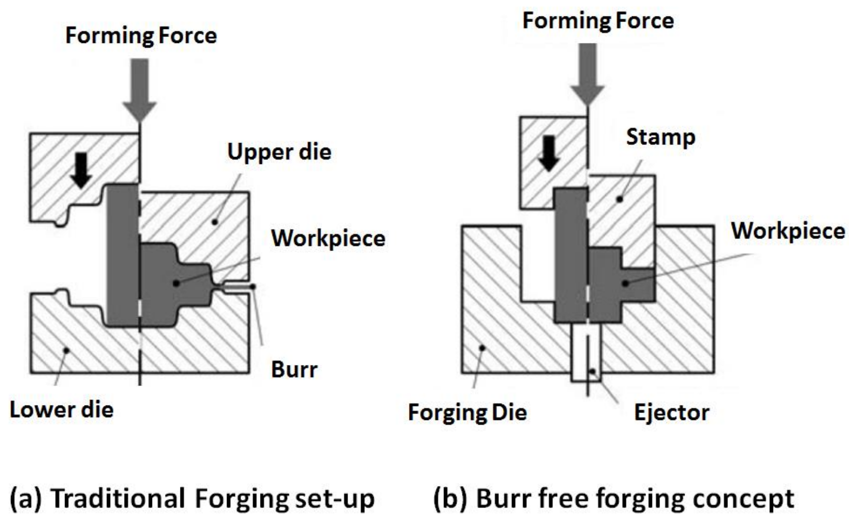

Figure 68. The adapted forging tools and the associated material flow in the burr free forging concept (b) leads to significant reduction or elimination of burr formation in comparison with the traditional set-up (a) (c) (IPH-Hannover, 2015)

Also 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 burrs. Whereas traditional forging tools only move in one dimension at a time, multi-directional forming tool allow for simultaneous movement of forming parts in multiple directions. This is important to guarantee for a high quality and flawless forging part with the right microstructure and materials properties.

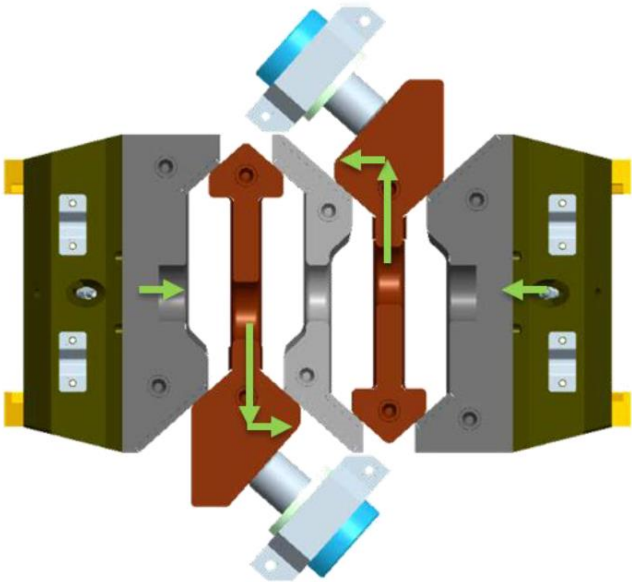

Figure 69. CAD model of a multi-directional forging tool for the forging of a crankshaft. The arrows indicate the multiple directions of moving tool parts (IPH-Hannover, 2015)

The tool design must be tailored to the required material flow. Finite element simulations allow to predict 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.

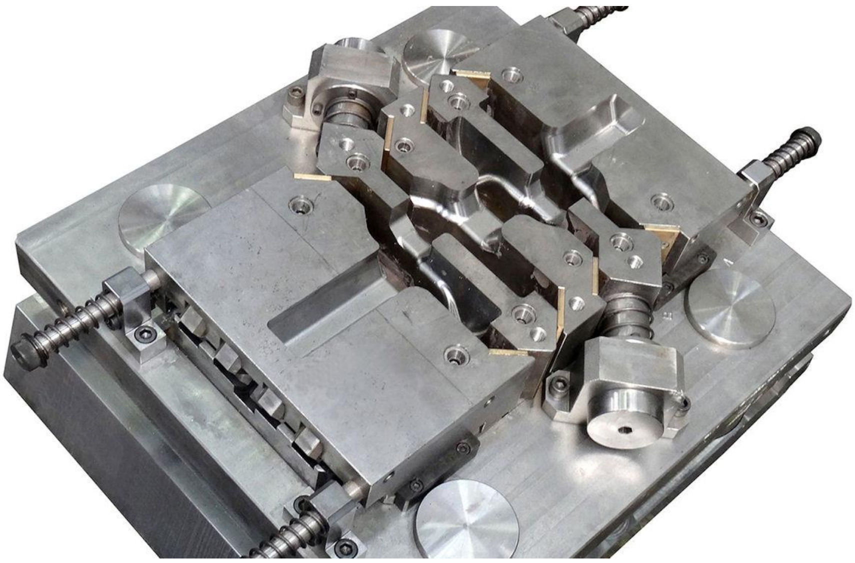

Figure 70. Example of a multi-directional forging tool. It not only presses metal into the form from above but also at the same time from the sides. (IPH-Hannover, 2014).

This tool can typically be used in normal eccentric presses to produce the parts.

Applicability

Multidirectional forging can be applied to a wide variety of materials (aluminium, copper, magnesium, titanium) and product geometries. Because of the need of a dedicated forging tool, this process is especially suited for the fabrication of larger series of complexly formed components.

Economics

Material costs usually accounts 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).

Driving force for implementation

Implementation of multi-directional forging leads to a saving of both material and energy resources. This also leads to cost savings from the moment that the start-up costs (development, tooling) can be leveraged over enough pieces. Consequently, both economic and environmental drivers are applicable

Reference organizations

Omtas (based in Turkey) – Producer of engine parts: http://omtas.com/
Omtas was one of the partners in the 7th framework project REForch; they implement the multidirectional forging.

IPH - Institut für Integrierte Produktion Hannover GmbH (spin-off of the University of Hannover): http://www.iph-hannover.de/de
The IPH - Institut fuer Integrierte Produktion Hannover GmbH is a company providing research and development, consulting, and training in production engineering.
Through investigating and improving production, they link the science of production engineering to the manufacturing industry. They are working with an interdisciplinary team of mechanical engineers, industrial engineers, business data processing specialists, technical economists, and technicians.

PCC (UK) – their Wyman-Gordon's Livingston facility in UK, supplies forged products globally to the aerospace and energy markets. It has a unique 30,000 ton hydraulic multi ram closed-die press at the heart of the operation, which is supported by heat treatment, material handling, etc. The 30,000 ton press is capable of multi-directional piercing and hot die forging of aerospace, power generation, oil & gas and nuclear components (asymmetric forgings, discs, seamless extruded pipe, valve bodies and hollow forged T's). It is the largest of its type in Europe, forging at temperatures of up to 1200°C. The 9,000 ton pre-forming press prepares the billet for the closed die forging process, ensuring a continuous smooth operation. CNC technology ensures repeatability throughout the entire forging operation. 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. http://www.ellwoodcrankshaftgroup.com/Vertical-Integration/Forging.aspx.

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2.3.7. Hybrid machining as a method to reduce energy consumption

Description

Within the sector, designers and engineers usually have multiple choices when it comes to machining technology. Depending on the part geometry, the material type and the lot size, a choice is made for different subtractive processes, such as drilling, milling, turning, grinding, and spark erosion. Besides the apparent speed, quality and geometric freedom related to each of these processes, their environmental impact is rarely considered at the design phase. However, the choice for one of these processes can significantly influence the energy use for the creation of a part (Figure 71).

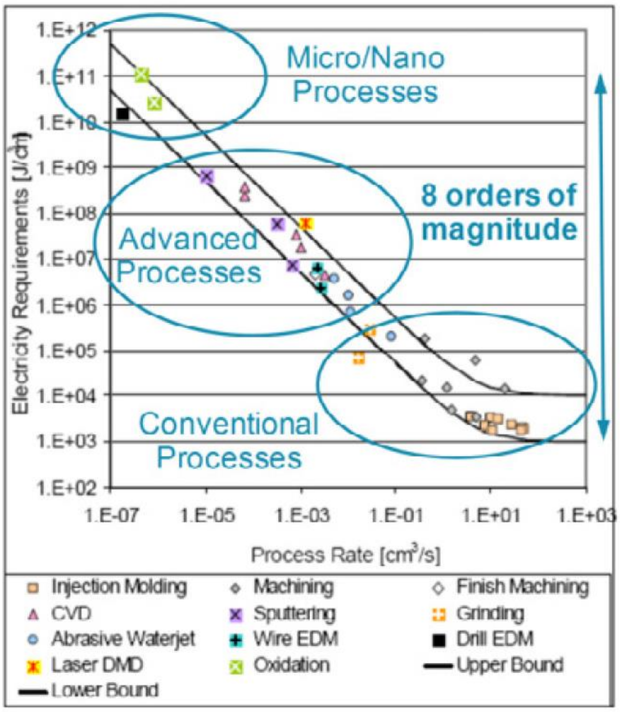

Figure 71: Electrical Energy Requirement for different processes (Gutowski et al., 2006)

Each technology has a certain process speed (cm^3/s) and specific energy requirement (J/cm^3), which eventually determine the overall energy use. However, functional part requirements, like surface quality, geometric constraints and material properties often limit the applicability of high speed low (specific) energy processes such as milling and turning. Manufacturing engineers responsible for overlooking the processes often choose one particular manufacturing technology based upon these functional requirements for the final product. However, applying hybrid technologies can significantly enhance the total energy requirement for the machining of a part. A hybrid machining process is defined as a manufacturing process which combines two or more established manufacturing processes into a new combined setup whereby the advantages of each discrete process can be exploited synergistically (Zhu et al. 2013).

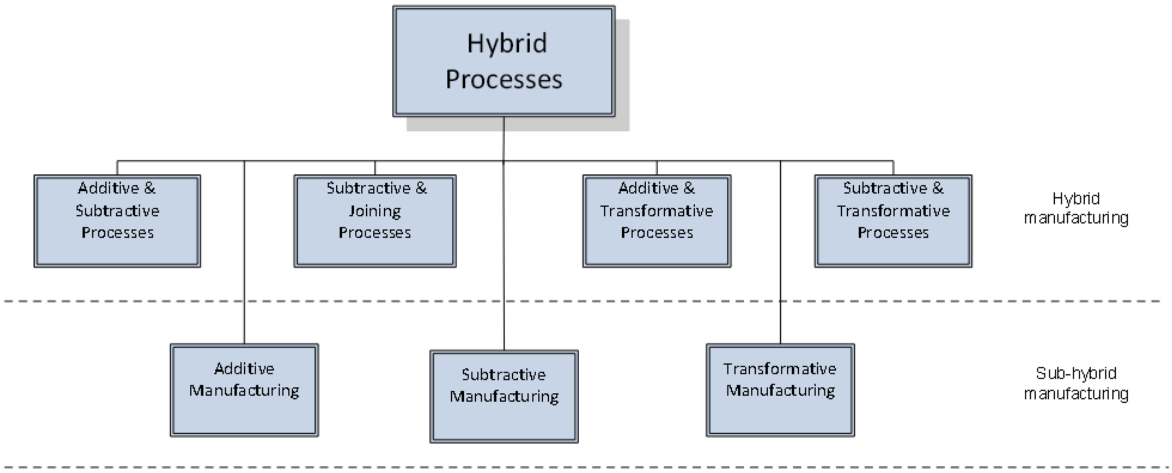

Figure 72: Hybrid process classification (Zhu et Al. 2013)

As can be seen in Figure 72 hybrid processes can be classified into several major categories, based upon the combination of machining technologies. 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. Transformation processes are e.g. laser softening, electrical discharge machining (EDM) and electrochemical dissolution (ECD). In practice this means for example that a mechanical conventional single cutting or media assisted (MA) action process can be combined with the respective machining phases of electro discharge (ED) in electro discharge machining (EDM) or ECD (Electro Chemical Dissolution) in ECM. The reason for such a combination and the development of a hybrid machining process is mainly to make use of the combined advantages and to avoid or reduce some adverse effects the constituent processes produce when they are individually applied. The performance characteristics of a hybrid process are considerably different from those of the single-phase processes in terms of productivity, accuracy, and surface quality. Furthermore, Zhu et al. (2013) states that hybrid processes open up new opportunities and applications for manufacturing various components which cannot be produced economically by processes on their own. Another approach on how to classify hybrid machining has been proposed by El-Hofi (2005). Depending on the major machining phase involved in the material removal, hybrid machining can be classified into hybrid chemical and electrochemical processes and hybrid thermal machining.

Using hybrid processes, existing technological process limits can be extended by combining additional sources of energy and conventional existing machining processes (Table 35).

Table 35. Examples of hybrid machining processes (Fraunhofer, 2014)

Principle	*Process variants*	*Motivation for application*
Vibration-superimposed machining	Drilling Turning Grinding	Improvement of chip breaking
	Electrodischarge Machining Electrochemical Machining	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

To achieve this, the machining process has to be broken down in different steps and the functional requirements for each step have to be listed. Based upon this, the most suitable technology for each step can be chosen taking energy consumption into consideration. In general, this will result in one or more roughing operations with one fast and energy efficient technology. While the finishing operation will be slower and more energy consuming, resulting in an overall lower energy consumption compared to the situation in which only the finishing technology is used based upon the functional requirements of the part.

Achieved environmental benefits

When combining energy efficient technologies (conventional processes as shown in Figure 71) with advanced processes compared to using solely the advanced processes there are several significant advantages:

- Lower lead times due to faster machining processes;
- Lower energy use and CO_2 emissions;
- More efficient use of consumables leading to less hazardous waste and emissions;
- Overall lower operating expenditure (OPEX).

Appropriate environmental indicators

An appropriate environmental indicator is the energy consumption (kWh machine consumption per batch).

Due to the synergies between the two interacting processes in hybrid machining, the overall machining process is more efficient than the sum of its parts. This efficiency is in general expressed in machining time, tool wear, spindle power, electrode consumption, cooling water consumption or compressed air consumption. These combined lead to less energy use during the hybrid machining process and less raw material use (resulting in an overall reduction of CO_2 emissions).

Cross media effects

Hybrid machining requires initially more investments in hardware and has therefore also an influence on the environmental impact due to the production of these machines. In addition, extra cooling water or compressed air circuits can be required for hybrid machining processes, offsetting the energy gains made by them. Care should be taken that these factors are taken into account when considering hybrid manufacturing.

The highest benefit is achieved if the different operations/processes can be installed on the same machining platform. When two separate platforms need to be used, the investment cost might offset the benefits.

Operational data

A good example is the use of a hybrid micro-milling/micro-edm system, as can be seen in Figure 3. The roughing operation is performed by micro-milling, which has a lower specific energy consumption compared to micro-EDM (electro discharge machining). The finishing operation, which is slower and more energetic, is performed by means of micro-EDM milling, since the accuracy and surface quality achieved with this technology is significantly better than with micro-milling. However, combining these two technologies leads to overall improved energy efficiency if only micro-EDM is used based solely upon the part requirements. In this case the Sarix SX200 platform is used to install sequentially the milling and EDM features.

Figure 73: Hybrid micro Milling/EDM machine (WZL, RWTH Aachen)

Applicability

Different subtractive and additive machining technologies can be used to machine or form a product. For example, hybrid lathes, which combine laser softening with turning, allow faster and more energy efficient material removal compared to either conventional turning or laser ablation. In general, this method can be applied to nearly all processes as long as the combination of technologies offers a substantial increase in performance and/or capabilities.

Economics

A substantial reduction in operating costs is expected due to lower lead times, less consumables, more efficient use of coolant/dielectric and lower energy use. However, additional investments are expected for the machine itself and/or additional infrastructure. An example for laser assisted machining (LAM) is shown in Figure 4.

Conventional turning with Carbide inserts is compared to conventional turning with ceramic inserts, both with and without the assistance of a laser which softens the material before chip formation. The result is a drastic reduction of 50 % for the machining of 1m of Inconel 718 using ceramic inserts compared to classical machining without laser assistance (Anderson et Al. 2006)

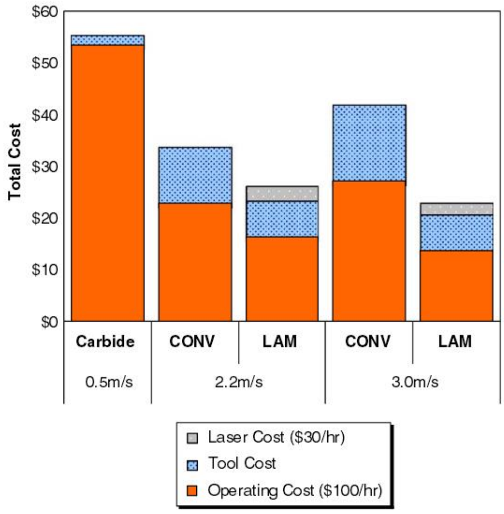

Figure 74: Conventional Machining vs Laser Assisted Machining (LAM) (Anderson et Al. 2006)

Driving force for implementation

Lower lead times combined with lower energy consumption are the main drivers for implementing hybrid machining in company in the metal fabrication sector.

Reference organisations

DMG Mori. DMG MORI integrates for the first time 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. 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. http://www.wzl.rwth-aachen.de.

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2.3.8. Machining of near-net-shape feedstock

Description

Integrated machining centres and milling machines start in general from generic feedstock shapes such as metal blocks and rods. However, by using these generic feedstocks a lot of unwanted material has to be removed and is lost as burrs. A possible solution for this is to start from near net shapes (Figure 75). Near net shapes are defined as products which initial production is very close to the final geometry, limiting the amount of unwanted finishing operations. Well known neat net production technologies are gel casting, injection moulding (ceramic, metal and plastic), casting, cold forming, spray forming, Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS). For example, injection moulding starts from powders (ceramics, metals) and results in a near net shape in which very often the only finishing is the removal of burrs, runners and/or machining within final tolerances. Up to 66% of the total production cost is hidden in this finishing operation, meaning that limiting them can be of great advantage for a company. In particular for expensive materials, such as titanium near net shapes are particularly interesting.

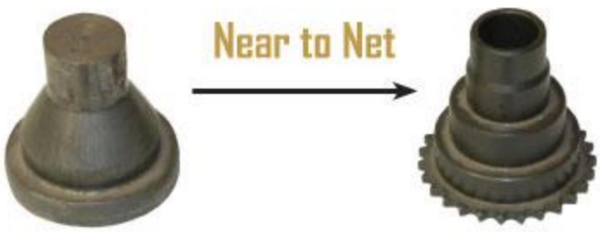

Figure 75: Near net shape machining (Whitesell group, 2015)

The feedstock material used depends on the type of near net shape process and the material. In the metallurgical processes, with exception of casting, a powder in which metal powders are mixed with polymer additives is formed, to a green compact and then sintered to achieve a solid near net shape (Figure 76). These products are Metal Injected Moulded (MIM). The powder composition, the size and the process conditions play an important role in the final product quality. They also influence the required finishing operations. Controlling shrinkage is for example vital to insure a minimum of stock remains for the finishing process.

Depending on the application and the material, a near net shape technology can be an option. Larger metallic parts are usually formed by means of casting, while mass produced smaller components are MIM’ed. In general, it is expected that by using a powder metallurgical process, the energy requirement to create the part material will be much lower, since this takes place far below the melting temperature of the metal and is based upon atomic diffusion and energy minimization (sintering). The majority of the near net technologies in metals are based upon this principle.

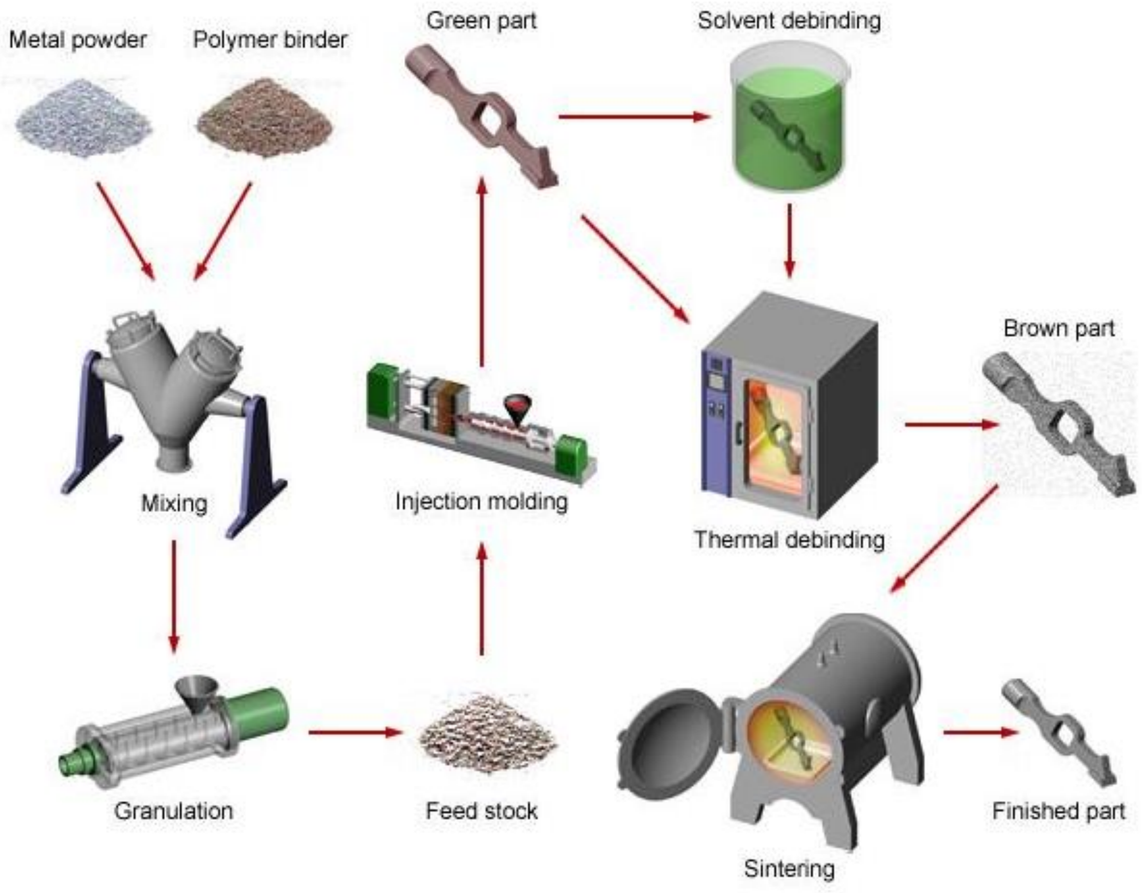

Figure 76: Flowchart of MIM (Afraz, 2012)

The use of near net shapes therefore does not only require knowledge regarding the suitability of a certain near net shape technique for milling or turning, but also a logistical approach. Designers and production engineers therefore should work closely together.

As the amount of burrs is reduced, the amount of non-hazardous waste is reduced. Traditionally this waste will be recycled to the ferrous or non-ferrous metals industry.

Achieved environmental benefits

The use of near net shapes greatly reduces the amount of lost material during conventional machining. In addition, due to the much lower machining time, the consumption of electrical power, coolant and compressed air and tool wear are significantly reduced. This is however offset by the additional energy and consumable use for creating the neat net shape.

The material and consumable savings result in a significantly lower amount of CO_2 emissions, lower amount of waste materials such as slags, refractories, electrodes, gases, etc. (Whitesell group, 2015; Plymouth, 2015).

Appropriate environmental indicators

The Percentage (%) of metals which end up in the burrs during the production of a metal piece is the appropriate environmental indicator.

Energy use and CO_2-emissions compared to machining conventional feedstocks due to less overall material removal can be measured by a LCA study.

Cross media effects

There are no negative effects on other environmental compartments due to the use of this technology.

Operational data

Suitable near net shaping technologies should be listed for each machining technology, together with material mass/cost, production cost. Ideally, a cost/kg for the finished product with near net shape should be determined and compared to the cost/kg when starting from a generic feedstock material.

The use of near net shapes greatly reduces the amount of lost material during conventional machining, which can mount up to 60-70 % of total mass in some cases (Whitesell group, 2015; Figure 77, Salvendy, G. 2001).

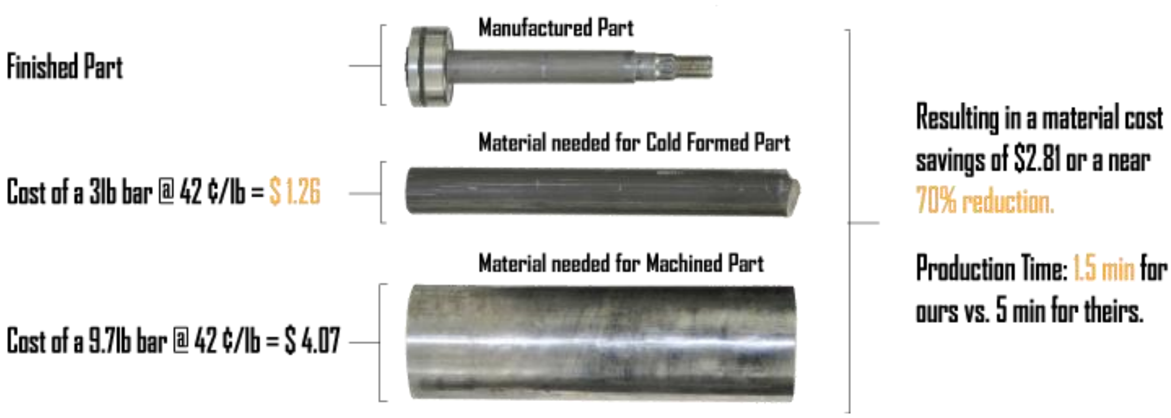

Figure 77: Cold forming as a near net shape technology to allow less material waste, lower cost and lower lead times (Whitesell group, 2015)

Applicability

Forged, cold formed parts, SLS and SLM sintered parts, injection moulded parts can be used as feedstock material for lathe's, milling machining, EDM and ECM to lower the overall environmental and economic cost.

The environmental and economic benefits depend greatly on the cost of creating a near net shape instead of starting from generic feedstocks and/or the cost for any additional logistical support such as robots to insert and clamp the part in the machine.

Economics

Lower machining times (up to 70 % reduction) combined with 60-70 % reduction in material use lead to significantly lower total costs compared to generic feedstock processes. This is offset by the cost for the creating the near net shape.

Driving force for implementation

Driving forces for implementation are:

- Cost reduction;
- Lead times reduction;
- Material availability.

Reference organisations

ASCO (Zaventem) is supplier and manufacture of high lift structures, complex mechanical assemblies and major functional components. ASCO uses titanium forge pieces instead of solid titanium blocks to lower machining time, tool wear, material waste and thus overall cost.

PMF industries (US) uses Near Net shape to produce different metal pieces for the food, pulp and paper industries, for medicals and other industries.
http://www.pmfind.com/

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Whitesell group, 2015, available online at:
http://www.whitesellgroup.com/product-coldformlarge.html, last accessed on 4th June 2015.

2.3.9. Reduce the energy for paint booth HVAC with predictive control

Description

In the BEMP 2.2.6 (Efficient ventilation), different steps for optimizing ventilation are described. One of the practices described is ventilation according to needs, by means of a central steering unit, which links data on machines with the ventilation valves (feedback control). The present BEMP focusses on the paint booth in the finishing step of Fabricated Metal Products companies, and will lead to a further reduction of the environmental impact of the heating, ventilation and air conditioning (HVAC).

HVAC for paint booths requires the highest energy consumption 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, and therefore a constant paint drying time.

Using forward controls on top of feedback controls to manage the optimal working conditions depending on the incoming air conditions (temperature and humidity), the energy needs can be reduced.

HVAC systems that automatically determine an optimal control point in accordance to the outdoor temperature and select the best energy-saving operation mode are already available. They are often called window control systems (Taikisha-group, 2015).

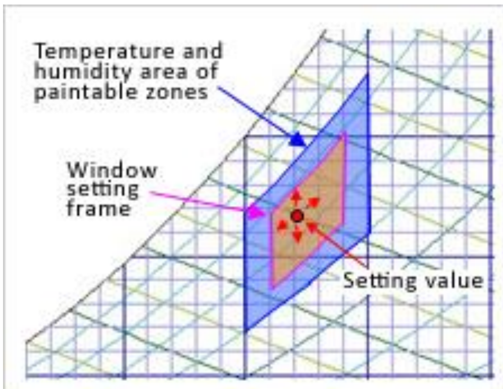

Figure 78. Control window versus control point (Taikisha-group, 2015)

Conventional water-based painting systems use air conditioning to maintain ideal conditions by keeping both the temperature and humidity at a fixed level. However, this consumes a considerable amount of energy, especially in summer and winter, to heat and cool the air inside and maintain humidity at the prescribed level. But the evaporation rate could also be controlled by adjusting the humidity level depending on

the ambient temperature in the paint booth. This means that it is no longer necessary to maintain a fixed temperature in the booth (Figure 79).

Based on this data, a system continuously controls the maximum water vapour absorption volume by monitoring the external air conditions and makes the smallest necessary adjustments to temperature and humidity inside the paint booth. The system significantly reduces energy consumption (Automotive manufacturing solutions, 2015).

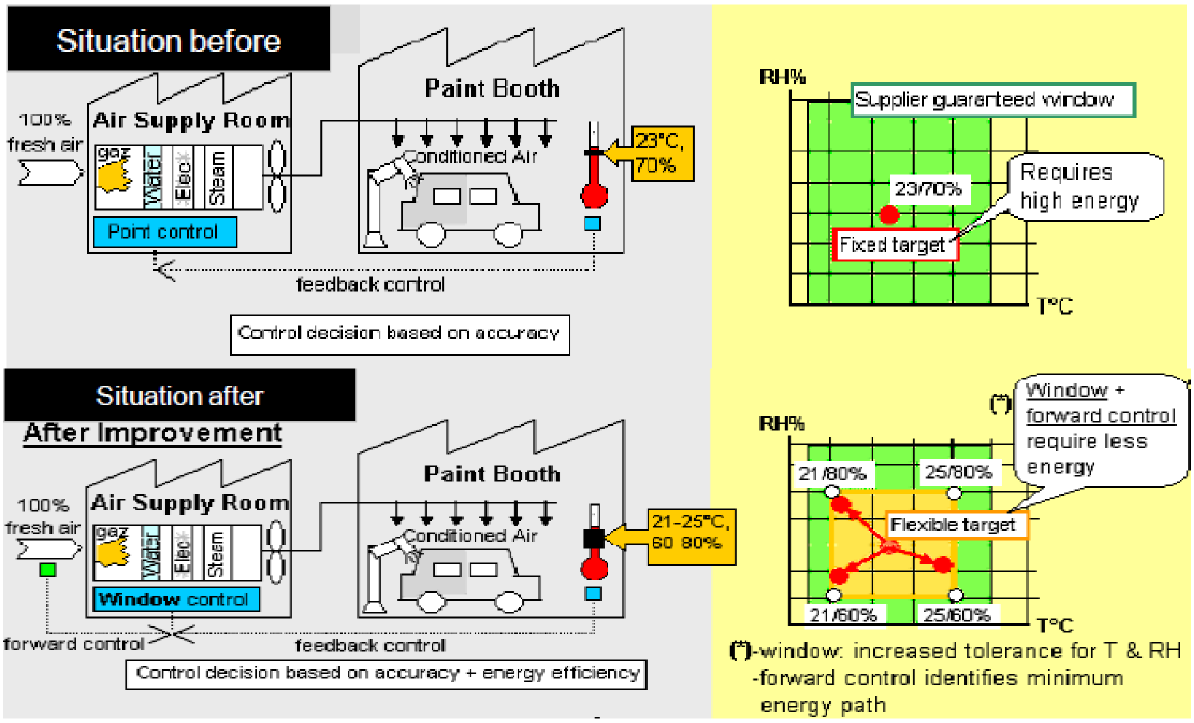

Figure 79. Situation before: situation of the paint booth with feedback control, Situation after: situation of the paint booth with forward and feedback control (Toyota motor manufacturing, 2015 –Personal communication at the Agoria event on automotive)

Achieved environmental benefits

By using this technology, less energy is needed for conditioning (heating and cooling) of air for the paint booth. This will lead to a reduction in CO_2 emissions and other emissions due to heating and cooling. In the Toyota case as shown in Figure 79this has led to a CO_2 emission reduction of 62% over 2 years.

Case Study: Honda Marysville, (VS, Ohio) (Kisiel, 2008)

Honda has developed a new air-conditioning control system that has cut energy consumption by 25% in the paint booths at the assembly plant here. Besides the reduction in energy consumption, Honda has realized a 24% CO_2 emission reduction from the natural-gas consumption in the paint shop.

Case study - Saab Automobile's factory in Trollhättan, Sweden (Rohdin et al, 2012).
In the Saab factory, a variable air volume (VAV) system was installed in the paint box. The total electric power use after the changes is 30.2%.

When this technology is combined with a change of paint type (water based instead of oil based) the technology could lead to a reduction in VOC emissions.
Due to a better control of the dry process, the total throughput of the paint booth could be achieved. Therefore this may lead to shorter curing cycles and eventually to an overall reduction of the energy use per produced unit.

Appropriate environmental indicators
Appropriate environmental indicators are:

- Energy use for the paint booth in function of the size of the painted units and the booth, kWh/product painted, kWh/operating time of paint boot or, kWh/per m³ air);
- Additionally the reduction in energy consumption can be translated into CO_2 emission reduction (which depends on the energy type used).

Cross-media effects
There are no cross-media effects due to the use of this technology.

Operational data
Mazda has 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. This has resulted in a 15% CO_2 emission reduction. Usually the process involves raising the temperature to 80°C until the paint is sufficiently dry. However, before the clear coat can be applied, the temperature must be reduced back down to 40°C. This can now be prevented. The technology means the water can be efficiently removed with the lowest possible electricity consumption (Automotive manufacturing solutions, 2015).

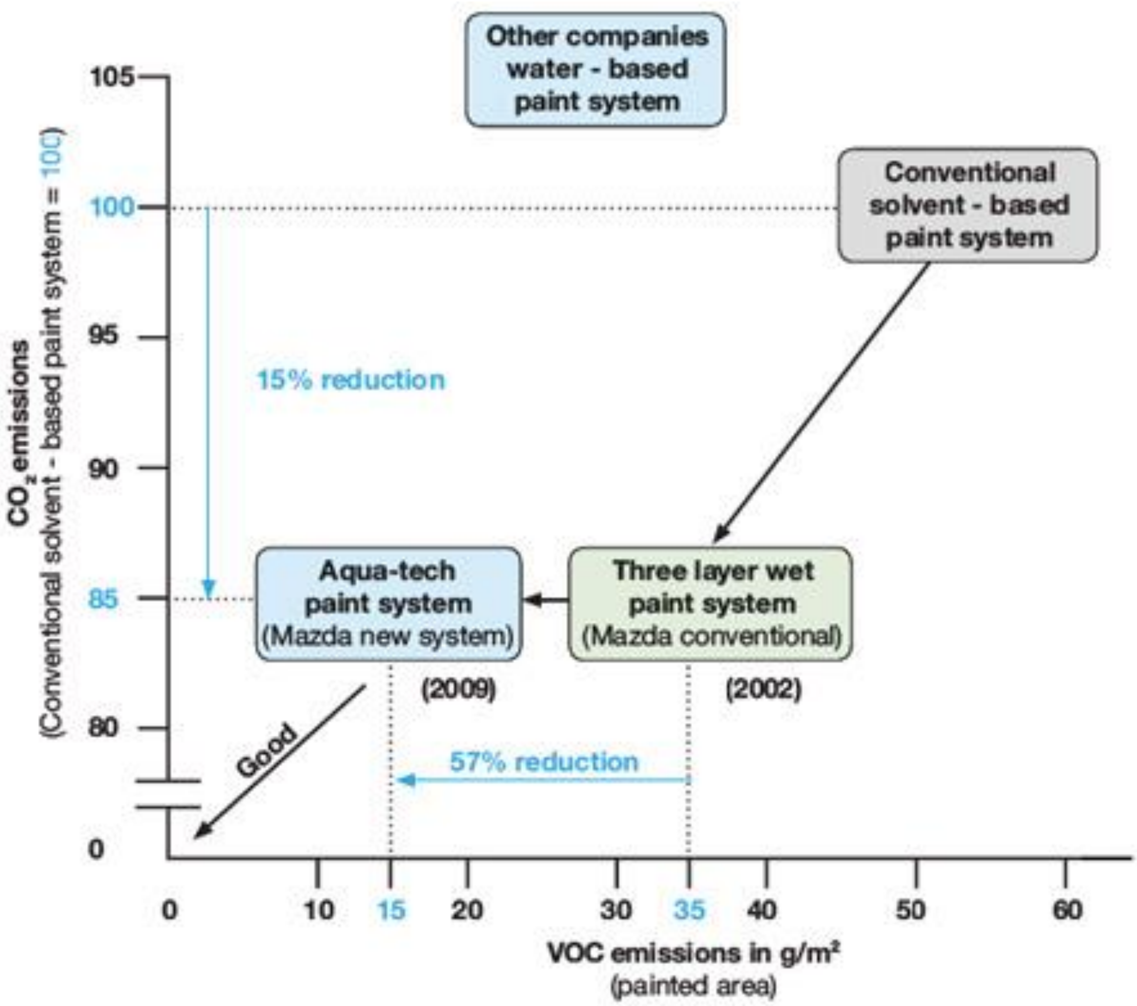

Figure 80. Reduction of CO_2 and VOC by the use of water based paint and forward control of the HVAC of the paint booth, comparing to conventional oil based paint and conventional drying technology (Automotive manufacturing solutions, 2015)

A comparable technology was installed at the Toyota plant in the UK. This has resulted in a CO_2 emission reductions of 65% (Toyota motor manufacturing, 2015 – Personal communication at the Agoria event on automotive; Honeywell, 2009).

Applicability

This HVAC system is more complex than the conventional ones due to the following elements:

- Qualified employees with profound knowledge;
- Maintenance and continuous follow up (sensor performance, etc.) to maintain the effectiveness of the installation;
- Strong and reliable data capturing (sensors, measuring, etc.) and automation.

The technology requires profound knowledge of paint drying process and paint quality control.

The technology is implemented in large paint booths using water based paints, but is probably not applicable for small size paint booths (no information on this available).
The investment and research costs are high, therefore, this technology is easier to be implemented from companies with multiple paint booths (on one or more locations) where the gathered knowledge can be valorised.
This is the reason why this technology is applied in automotive companies and no published case are found (yet, reference year 2015) in other Fabricated Metal Products companies.

Economics

At Toyota Motor Manufacturing(UK) the energy use in the paint booths was reduced by 25%. This equates to a saving of 4% of the site's total energy consumption. Toyota Motor UK 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 organizations

Toyota Motor Manufacturing (UK) Ltd, Toyota implemented the technology in the UK plant.
http://www.toyotauk.com/

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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2.3.10. Selection and optimization of thermal processes for curing wet-chemical coatings on metal products

Description

Surface treatment with functional coatings is performed in the Fabricated Metal Products sector to upgrade a (metallic) surface and provide it with an additional functionality. The additional functionality can be e.g. scratch resistance, abrasion resistance, easiness to clean, anti-microbial, soft-touch, etc. The use of a coating is always an extra step in the manufacturing process. It requires additional effort to apply, but also to cure the coating. This extra step requires an additional energy input. Therefore, carefully selecting and optimizing the proper curing process for a given product can lead to significant energy reduction. Curing of coatings can be done in various ways depending on the chemical composition of the coating: The industrial most significant techniques are:

1) Room temperature curing;
2) High temperature curing;
3) Infrared curing (IR curing);
4) UV and UV-led curing.

1) Room temperature curing

Curing at room temperature is the easiest way for curing a coating, but the formulation has to be made accordingly. Conventional decorative paints cure at room temperature for example. They are not used for large series in an industrial process because of the time needed to cure the coating, in case of unique pieces or small series, room temperature curing is used in the sector.

2) High temperature curing (hot air/convection)

Conventional curing with hot air requires a lot of energy for heating up the air around the coated surface. Curing with hot air is the least favourable way of curing (in terms of energy use). But it is easy to apply and all kinds of difficult geometries can be covered with this curing technique.

Typical curing temperatures can range from 60 up to 200°C depending on the coating formulation. High solids coatings only need al short flash-off and curing while formulation with high solvent content need longer curing.
Where time is not a critical parameter, thermal cure coatings can cure on a lower temperature during a longer time, while the same coatings can be forced cured at higher temperatures needing less time to fully cure. The first way of approach obviously requires less energy which makes this the most sustainable option.

3) Infrared curing (CCI Thermal, 2015)

Heating with infrared energy heats up the object by irradiation, and thus the coating is cured from the inside out, whereas curing with hot air cures the coating for the outside inwards. For thick coatings this can lead to cracking because a hard thin film is formed at the surface while the rest of the coating is not yet cured. Remaining solvents in the coating need to escape and have to find a way through the formed hard shell leading to cracks.

The radiant energy of infrared heat is ideally suited to the process of finishing because the infrared radiation heats from the inside out, ensuring that water or solvents are forced to the surface and evaporated so they cannot cause blemishes and blistering. The infrared heating process is the purest and most direct application of heat. Since infrared energy heats only what needs to be heated - the product and the coating - less energy and time are required. Infrared curing avoids circulating dust particles that can ruin the product's finish - unlike conventional convection methods that are unreliable to control finishing results. Infrared curing, as occurs in an industrial oven application, applies radiative energy to the receiver, or part, by direct transmission from the emitter. Some of the energy emitted will be reflected off of the part surface, some is absorbed into the coating and some is transmitted into the substrate. Infrared emitters provide a fast cure for coatings but they are sensitive to differences in the part structure.

IR radiation is a line-of-sight technology, meaning that it only delivers heat to the surface of an object that is in a direct line of sight from an IR source. When using complex geometries, with parts that cannot be irradiated with IR, a combination of IR curing and conventional thermal curing is an ideal solution. Those hybrid systems try to combine best of both worlds, e.g. hot air infrared drying system (HID). This HID system leads to an effective heat management and has several benefits (IST, 2015):

- With the HID system it is possible to achieve production speeds, which are twice as fast as with conventional warm air dryers;
- A combination of high power IR lamps and a high volume of hot air result in an extremely effective drying system;
- Effective heat management guarantees the optimum temperature on the substrate for accelerated drying;
- The finely tuned air slit nozzles and exhaust unit ensure effective removal of the moisture from the substrate.

4) UV and UV-led curing

Curing with hot air and IR can take a while (negative aspect), while curing with UV hardens the coating in merely seconds. Curing with conventional UV (gas discharge) also demands high energy input, while curing with UV-led demands much lower energy input. But there are currently only a handful of coating formulation which can be cured with UV-led (Koleske, 2002). The UV-curing technology enables ultra-rapid curing at room temperature, saving considerable time and energy. The coating formulation has to be formulated accordingly in order to apply UV curing. Curing with UV needs the presence of photo-initiators in the coating. The coating curing forms a systems that might require significant process changes and investments. UV-led curing however is not yet completely integrated because the conventional curing with UV discharge lamps are more efficient. Also the photo-initiations needed for UV-led curing still have to be optimized further to ensure complete curing/polymerization of the coating. UV led compare to convention UV curing has some advantages as shown in Figure 81.

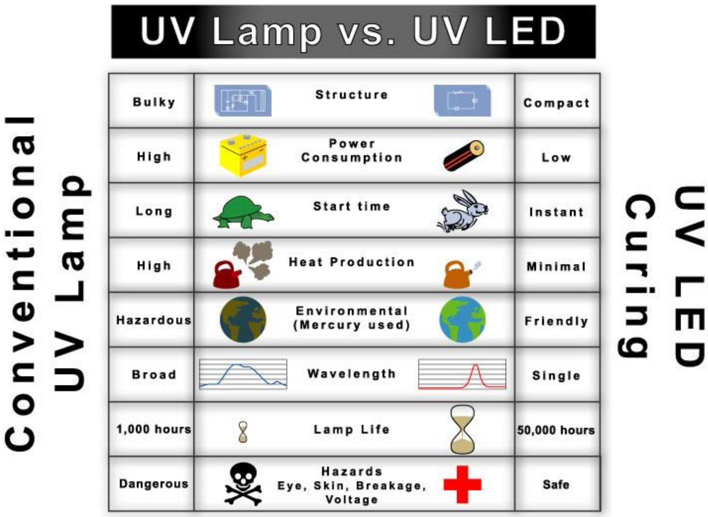

Figure 81. Differences between a conventional UV lamp and a UV led for curing (UV process, 2015)

Achieved environmental benefits

Conventional curing with oven (hot air) is least environmental favourable since warming up air requires a significant amount of energy. It is clear that the good selection and optimization of a curing technology for a given product/process will lead to significant energy reductions.

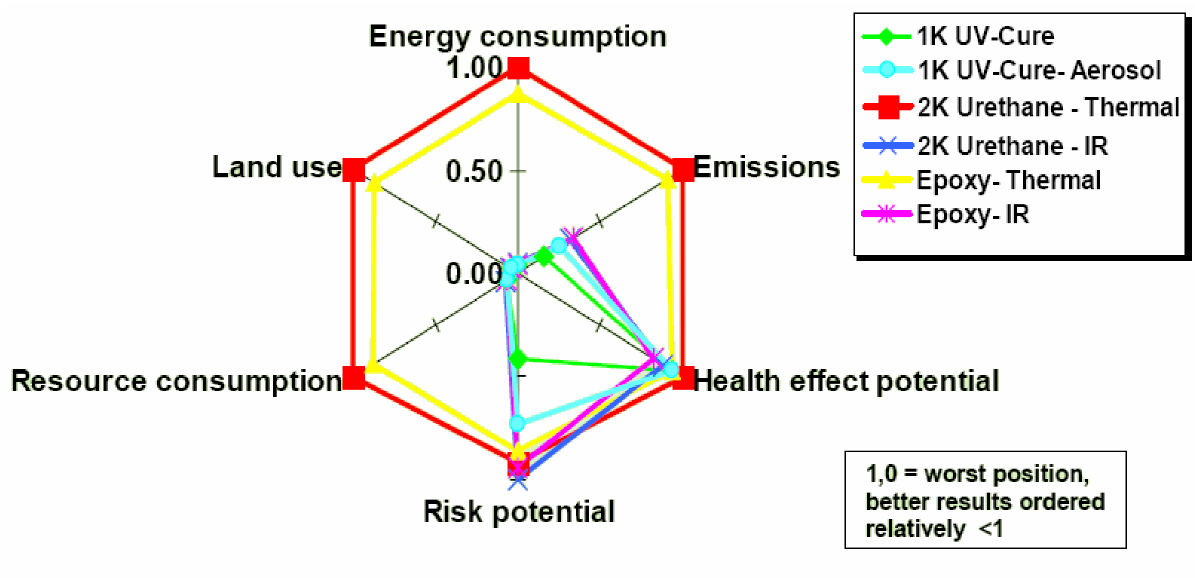

Figure 82. Ecological fingerprint of six refinish primers (Wall et al., 2004)

Appropriate environmental indicators

Appropriate environmental indicators are:

- Energy use for curing (kwh/m² coating cured);
- VOC emissions: in case of UV and UV-led curing is introduced, VOC elimination can be achieved. Solid content determines the amount of VOC emitted. Typical

hot air cured coatings have a solid content of 30-60%, while UV cured coatings have a solid content of ~90-99%.

Cross-media effects

Coatings that have to be cured with hot air or IR are mostly low solid content coatings, which are water based or solvent based coatings. Solvent based coatings have high VOC content (volatile organic carbons) during curing, leading to a higher environmental impact. Increased awareness of environmental impact and VOC and more regulatory requirements in most European countries have led to an increased demand for more sustainable organic coatings, including for applications on metallic substrates. Therefore, the market share of solvent based coatings is decreasing in favour of more sustainable alternatives. Water based coatings and UV-hardening coatings are possible alternatives.

Curing with UV requires the presence of photo-initiators in the coating which trigger the polymerisation process in the coating. When this polymerisation is not fully controlled, e.g. due to over-concentration of photo-initiators or inadequate UV exposure, they can leach out the 'cured' coating. The concentrations of those leached out photo-initiators are extremely low. However, special attention is required, especially since they can be toxic. This is the reason why for food and medical application UV-curing coatings are not yet approved. Many photo-initiators or monomers are not, or only partially, trapped in the cured ink film and still remain capable of migration to foods, depending on their molecular weights. Likewise, decomposition products that are formed during the curing reaction and that are not trapped in the ink film may be a source of migrating chemicals. The majority of photo-initiators have not been toxicologically evaluated for food contact application (Sutter et al., 2011).
Selection of the UV-curable ink components and ink solvents has a significant impact on hazardous waste, skin irritation, toxicity etc. (Table 36).

Table 36. A comparison of the toxicity & other properties of UV-curable ink components and some commonly used ink solvents (PNEAC)

Chemical	Flash Pt.	VOC	Hazardous Waste	Community Right to Know List	Systemic Skin Irritant	Toxicity	Reproductive Effects
TMPTA	>212° F	No	No	No	Yes	No	No
Oligomer	>>212° F	No	No	No	Maybe	No	No
VM&P Naphtha	<0° F	Yes	Yes	No	Yes	Yes	No
Toluene	40° F	Yes	Yes	Yes	Yes	Yes	Yes
Xylene	100° F	Yes	Yes	Yes	Yes	Yes	Yes
1-Butanol	100° F	Yes	Yes	Yes	Yes	Yes	Yes
2-Butoxyethy Acetate	190° F	Yes	Yes	Yes	Yes	Yes	No

Operational data

Golden (2005) reviewed some case studies related to the application of technologies for curing coatings. In an organization where surface treatment is applied to aluminium cans, the original technology (thermal curing of water-borne coatings) was replaced by an UV-curing process. Even the water-borne coatings contained substantial quantities of VOC that had to be incinerated. Table 37 shows that although incineration controls with water-borne inks and coatings can achieve the same level of VOC and HAP emissions as UV curing, this is at the expense of increased emissions of hydrocarbons (HC) and carbon, nitrogen and sulphur oxides.

Table 37. Total industrial installation and utility source emissions (metric tons/billion cans) (Golden, 2005)

	Process		
Emissions	*Water-borne Thermal, uncontrolled*	*Water-borne Thermal + incineration*	*UV curing*
Nitrogen oxides	8.1	11.6	6.5
Sulphur oxides	18	23	18
Particulates	25	29	24
VOC	28	0.56	0.52
HAP	11.5	0.23	0.12
CO_2	2,909	5,182	1,727
Ozone	Not measured	Not measured	0.0019*

* at the UV oven exhaust

Similarly, Table 38 shows the substantial additional energy cost for the controlled water-borne system to achieve the same low level of emissions as the UV installation.

Table 38. Total industrial installation and utility energy use (million BTU/billion cans) (Golden, 2005)

	Process		
Emissions	*Water-borne Thermal, uncontrolled*	*Water-borne Thermal + incineration*	*UV curing*
Electricity	16 300	19 500	15 900
Natural gas	23 900	60 100	0
Total	40 200	79 600	15 900

Applicability

When using the right pre-treatment and primer system, any metallic object can be coated with a wet chemical coating. Interesting about coating technique is that it is an additional technology. Almost every company in the sector can, at any time, start to incorporate coatings in their products or processes. Due to the existence of job coating companies, even the investment of coating technology and knowledge is not necessary.

Changeover to U-cured coating systems requires changes to the coating application processes. Even if coatings are applied by jobcoaters, tests and selection procedures need to be performed in advance. This together with the often required selection of a new supplier (jobcoater) increases the threshold for this application. Moreover transferring the environmental impact of the process towards supplier companies can tend to reduce their environmental requirements.
Certain production parameters need adaptation to get the highest performance with the coated products. Employees need to be aware that products have a coating and pre-treatment of the tool in production could need an adaptation.

Economics
In general a higher added value due to the introduction of new surface functions can considerably increase competitiveness. It has been estimated that a 5% increase in added value due to innovative surface technology compensates a 20% lower cost of manufacturing in foreign countries. The added value of using the appropriate surface treatment technology is estimated at ca. 3-7% (Stenzel and Rehfeld, 2011).
Powder coatings cured with UV are 100% solids, while liquid paints have a reduced solid content (solvent borne paint about 40–45%, waterborne paint about 40%, higher solids about 65%), and need viscosity adjustment generating extra handling costs. Transfer efficiency of powders is 95%, and nearly all powder over-spray can be recycled or reused.

As powder coatings are solvent free, lower airflow during curing is required. For wet paint, high airflow is required for curing and volatile removal. This results in higher energy costs.

Powder coatings are ready to use as delivered, do not require online viscosity adjustments or testing. Higher operating efficiency. The use of powder coatings allows closer line spacing (no solvent evaporation) with lower rejection rates, leading to a higher operating efficiency (PCI, 2000).

Driving force for implementation
Main driving forces for implementation are:
- More efficient energy use;
- Higher quality products with additional functionality;
- Added value products;
- Faster throughput time with UV coatings.

Reference organizations
Ridley bikes - coating on metallic frames.
http://www.ridley-bikes.com/be/en

Trislot. Trislot's focus is on providing highly specialized filter elements and reactor internals to key players in various industries - coating on metallic filter elements.
http://www.trislot.be

Art Casting – protective coatings on Si-bronze.

http://www.artcasting.be

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https://www.uni-goettingen.de/de/document/download/03272d0c4424097d5a314b06f02426d1.pdf/08_10_Quantifying%20Eco-Efficiency.pdf, last accessed on 29th May 2015.

2.4. Concurrent engineering and product design as Best environmental management practice

2.4.1. Remanufacturing of high value components

Description

Remanufacturing is an industrial process whereby used products are restored to useful life. Remanufacturing involves a series of steps returning a product or product part to like-new state / performance performance, with a similar or extended warranty to match. Remanufacturing differs from recycling. As with all product reuse options, remanufacturing involves preserving the whole form of products. Recycling requires the destruction of products to its component materials so they can be melted, smelted or reprocessed into new forms. These new forms can be the same products (called closed loop recycling) or new ones (open loop recycling) (CRR, 2015). Furthermore, remanufacturing differs from reuse whereby whole products or product parts are used again in one piece (Figure 83).

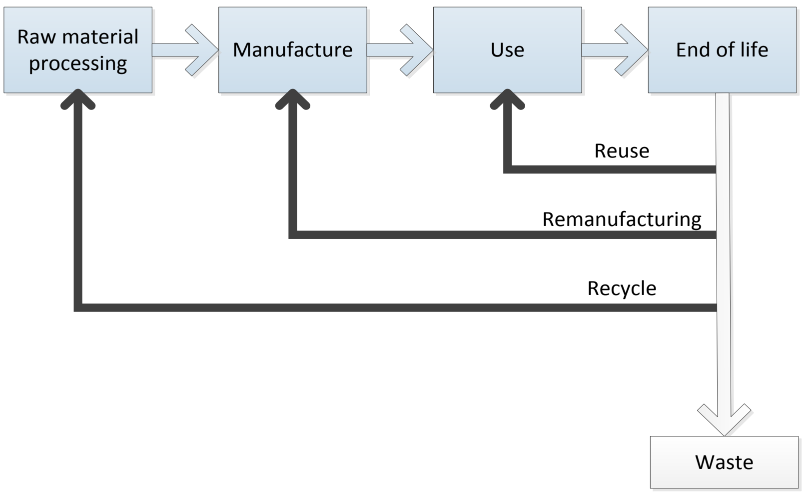

Figure 83. Remanufacturing, restoring used products to useful life (CRR, 2013)

Materials constitute 40 to 60%of the total cost base of manufacturing firms in Europe (McKinsey, 2015). For Fabricated Metal Products companies this means that remanufacturing products or their components has a significant cost saving potential. Remanufacturing of products or their components allows Fabricated Metal Products companies to generate (new) business without transforming raw materials into new products or components. Next to having higher direct material cost, primary manufacturing processes are in general more labour and energy intensive than remanufacturing processes. Remanufacturing leads to a lower material and energy use, which results in a lower environmental impact.

There are many sectors in which remanufacturing can be applied, but sectors like the automotive and sectors producing investment goods like heavy duty motors, pumps, compressors, gearboxes, etc.; have the highest potential (Fraunhofer, 2013). The

various products (in general high value components) which are remanufactured or have a high potential to be remanufactured are for example (CRR, 2015):

- Machine tools;
- Electrical motors and compressors;
- Automatic transmissions;
- Car and truck engines and their components (compressors, pumps…);
- Air-conditioning units;
- Pumps;
- Industrial food processing equipment;
- Aerospace.

In general, remanufacturing is a series of steps of which the sequence can be different depending on the products. The most important steps, included in almost every remanufacturing process, are (Fraunhofer, 2013):

- Collection of products to be processed;
- Disassembly of product;
- Cleaning of parts;
- Inspection and sorting of parts;
- Reconditioning of parts and/or replacement by new parts;
- Product reassembly;
- Final testing.

Figure 84 presents the relation between the various remanufacturing steps and the preferable product properties. Although it is important to have the whole remanufacturing process in mind when designing products for remanufacturing, this matrix can be used as a design tool by means of which the designer can easily find out what properties are needed for the different steps (Gray, C. and M. Charter, 2007).

Remanufacturing Step / Product Property	Inspection	Cleaning	Disassembly	Storage	Reprocess	Reassembly	Testing
Ease of Identification	×		×	×			×
Ease of Verification	×						
Ease of Access	×	×	×		×		×
Ease of Handling			×	×	×	×	
Ease of Separation			×		×		
Ease of Securing						×	
Ease of Alignment						×	
Ease of Stacking				×			
Wear Resistance		×	×		×	×	

Figure 84. The RemPro-matrix showing the relationship between the preferable product properties and the generic remanufacturing process steps (Sundin, 2004)

Easy disassembly results in shorter disassembly times and higher recovery rate of intact parts. Design for disassembly is therefore an important component of design for

remanufacturing. Where remanufacturing is suitable, design for remanufacturing may improve the efficiency of remanufacturing by:

- Reducing disassembly and reassembly times and thereby also reducing inspection/evaluation time and costs. Standardisation of securing methods like screw types and threading, seals, etc. For example: The BMA ergonomic chair is assembled and disassembled on the same production line in 16 min. BMA applies a take back business model which provides the customer an incentive to return the chairs (Figure 85).

Figure 85. BMA assembly – disassembly line (BMA-ergonomics, 2015)

- Specifying materials and forms appropriate for repetitive remanufacture. Steel alloys are in general very good and sustainable material with high potential for remanufacturing: materials wear, hardness, form stability, possibility to clean and corrosion protection.
- Building mechanisms into the product or component to ensure the return of cores. For example: Separating the wear component from the structural components is a successful approach (Gray C. and M. Charter, 2007).

On the technological side, the product design and the process of remanufacturing should result in a perfect valuable product and meet all the required technical specifications required of the original part/product. Therefore, each of the remanufacturing process steps will require a case-specific investigation and the process sequence steps might differ from the classic production process (Butzer and Seifert, 2013):

- Collection: Reverse logistics, sorting and batching;
- Disassembly: Optimization of disassembling, tooling, automation and modular processes;
- Inspection: Product/component integrity;
- Cleaning & Storage: Sand blasting and degreasing;
- Remediation: Welding, applying new coatings, replacement parts and building packages;
- Reassembling: Assembling;
- Testing: functionality and integrity.

Achieved environmental benefits

Remanufacturing of high value components is a resource efficient process. By remanufacturing high value products or components the embodied energy can be preserved and production waste can be reduced. These two aspects have an immediate impact on the CO_2 emissions related to the products. Sundin (2004) indicates 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.

Case studies clearly indicate the environmental and economic benefits of remanufacturing of high value components in the metal fabrication sector.
At Caterpillar, within the UK-based operation for EMEA, remanufacturing was already initiated since 1972. In total 43 million tonnes of core materials were reused, leading to up to 90% cost savings over new materials and to ca. 52 million tonnes of CO_2 avoided (Walsh, 2013; Caterpillar, 2015).

A reduction of CO_2 emissions of 30% to over 50% are reported for typical automotive parts compared to new products (Fraunhofer, 2013).
An example of remanufacturing starters and generators indicated annual savings (compared to the production of new components) of ca. 88% energy (~ 85,000 MWh) and significant amounts of metals (e.g. 200 ton copper and 350 ton aluminium) (Schlosser, 2011).

Appropriate environmental indicators

Appropriate environmental indicators are:

- The amount of the remanufactured components per product sold (weight/products);
- The percentage of the products sold without remanufactured components out of the products sold with remanufactured components.

The embodied energy that can be preserved or the amount of CO_2 emissions reduced, e.g. relative reduction compared to new products, %. The embodied energy can be calculated (often supported by external knowledge or competence centres) comparing the embodies energy or semi-quantitative environmental impact of new versus remanufactured components. Having this investigation performed provides an insight in the impact. This is a quantitative approach.

Cross-media effects

Remanufacturing case studies show that the companies performing remanufacturing often have problems with material flows, use of space and high inventory levels. This is often due to the uncertainties in the quality and the number of used products suitable for remanufacturing. To overcome these problems, the remanufacturers need to achieve a better control over the product’s design and use phase, i.e. the life cycle phases that precede the remanufacturing process. This lead to additional space requirements (e.g. warehouses) (Sundin, 2004).

Operational data

Case study: ZF Belgium (BE) – truck transmission refurbishment

At ZF Services Belgium, specialized in truck transmission refurbishment, in total over 1,700 transmissions types exist. Creating stock for each of those types appeared not to be cost effective. Manufacturing new parts was not possible to keep on time delivery. With the recuperated parts approximately 20 standard packages are composed. Those packages are composed in such a manner that they allow to refurbish the over 1,700 varieties of transmissions in a short time. This results in a service level of 100% within 24 hours instead of the 7% before. Meanwhile the total number of varieties increased to 3,000, without impacting the service level. A cost reduction of 20% is realized (Industrie - Technisch & management, 2011).

Case study Portal Power (UK) – portal frame buildings

The main activities of Portal Power, are the design and erection of portal frame buildings. Over 40% of their 2,000 – 3,000 tonnes annual throughput is pre-used portal frame buildings. Portal Power oversees the whole process from deconstruction, through any modification to final erection in a new location. After deconstruction, Portal Power stores the steel while waiting for a buyer. When a customer is found, Portal Power can modify the building, adding value to their business (Allwood, J.M. et al, 2012 and Portal Power, 2015; Figure 86).

Figure 86. Steel waiting for a buyer at the Portal Power plant (Allwood, J.M. et al, 2012 and Portal Power, 2015)

Case study Rype Office (UK) – office furniture – three business models

Rype Office (Figure 87), offers three furniture options for customers: New, remade or refreshed, each appealing to different client preferences and openness to new business models and remanufactured products.

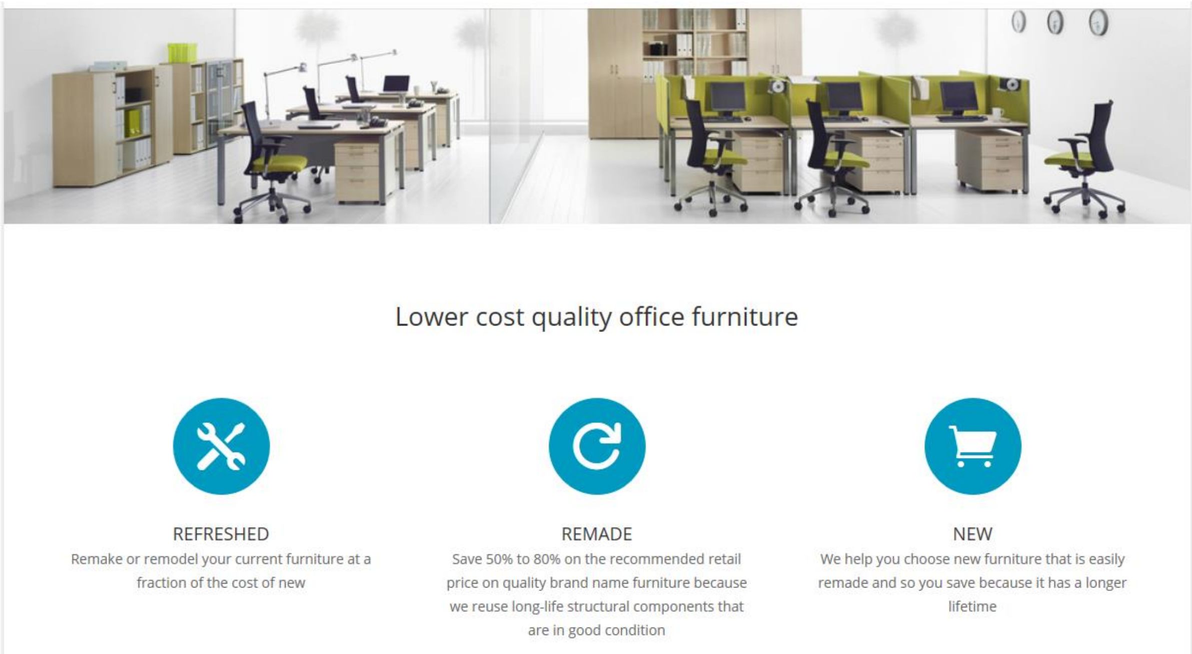

Figure 87. Rype Office offering (Rype Office, 2015)

For customers who desire brand new furniture, products can either be purchased outright with the option of a buy-back offer, or leased for a monthly fee. Both allow Rype Office to recover the furniture for remanufacturing at the end of its first life, while saving customers money. The furniture offered by Rype Office in this model has been chosen for its quality and ability to be remanufactured, reducing the cost to renew it.

Applicability

Although there is a large variety in products which can be remanufactured, it works best for the Fabricated Metal Products sector if the products are of high value, complex and durable.

Areas where remanufacturing is successfully applied or has a high potential to be applied are (Fraunhofer, 2013):

- Automotive industry. Automotive parts represents by far the largest opportunity for remanufacturing. Although in Europe the large variety of products makes refurbishment a challenge;
- Investment goods (heavy duty motors, pumps, compressors, gearboxes, etc.). Especially investment goods with high material content (weight, volume and price) and large embodied energy (casting parts, parts with complex forms, parts with expensive materials, etc.) are very suitable for remanufacturing.

Important barriers for implementing remanufacturing in the sector are existing regulation and standards dealing with “as new” products, the general market focus on the quantity and recycling of products and customer trust (quality, warranty and regulations).

Remanufacturing has a role in enabling extended producer responsibility. But remanufacturing is under threat from low cost imports of improving quality goods from abroad. Perception of remanufactured goods as 'second-class' can limit sales growth in, e.g. fashion-oriented, lifestyle or status products: cars, white goods, attire. Even business to business transactions suffer without strong standards for the remanufacturing process. Remanufacturing has the potential for even greater contribution to sustainable consumption, and there are steps that all stakeholders can take to enable this. A starting point is elimination of legal impediments such as denial of access to manufacturer design information, banning of remanufactured components in new goods, and redefinition of what constitutes waste. Removal of these would increase competition and force evolution of improved services, including remanufacturing (CRR, 2015).

Investment goods have the largest potential for remanufacturing. Logistics and technical feasibility to remanufacture the products play an important role. Therefore the product design has a large impact on the remanufacturing efficiency.
Remanufacturing leads, in most cases to additional space requirements, to avoid this smart stock solutions or product combinations can be an option (see ZF Belgium case).

Economics
The implementation of remanufacturing of high value components can lead to cost savings both for the organizations and the consumers. Depending on the product and the intrinsic value of the parts, the savings for consumers can go up to 90%. From the perspective of the companies, remanufacturing leads to lower costs compared to manufacturing from raw materials. Organizational changes can even further reduce costs (ZF case 20% reduction) and in general the margin on remanufactured parts are higher compared to new parts (Fraunhofer, 2013).

Remanufacture can offer a business model for sustainable prosperity, with reputed double profit margins alongside a significant reduction in carbon emissions (OHL, 2004) and 15% of the energy required in manufacture (Steinhilper, 2006).
A successful remanufacturing strategy (Figure 88) implies often new business models (green label, product guarantee, involvement of distribution channels, leasing, take back systems, etc.), adjusted product design (modular, etc.) and performant manufacturing system (i.e. short delivery times, effective logistic loops, building packages dealing with complexity, etc.) (Sirris/Agoria, 2015).

Figure 88: Remanufacturing requires different aspects in the "three basic components of industry" to be balanced (Sirris/Agoria, 2015)

Depending on the sector, remanufacturing can have an impact on the EBITDA (Earnings before interest, tax, depreciation and amortisation and is a profit metric measured by companies in. It does not account for the additional capital expense required to establish remanufacturing, which would comprise the space and equipment to disassemble products and cleaning and refurbishment equipment) and number of jobs (Figure 89). Different Fabricated Metal Products companies are active in the machinery, equipment and transport equipment.

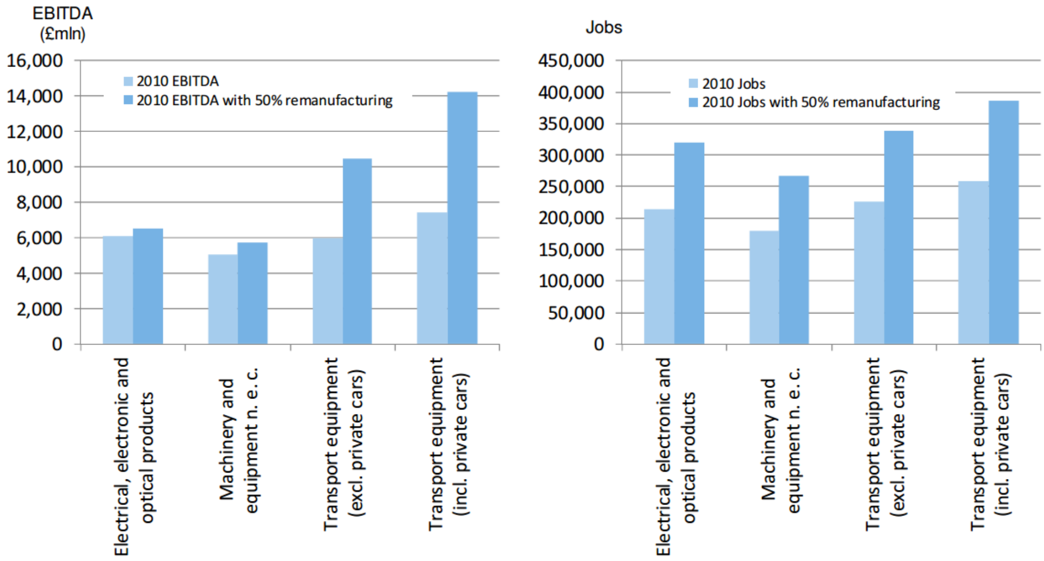

Figure 89. Impact of full remanufacturing on EBITDA and jobs in four sectors in the UK (Lavery et al, 2013)

Driving force for implementation

Remanufacturing of high value components in the sector is a practical example of the circular economy, leading to an extended product-service. The economic (cost reduction and increased revenue) and environmental benefits (material and energy efficient process leading to reduction in CO_2 emissions) are the main driving forces for implementation.

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Punch Power Train. Punch Powertrain offers a complete portfolio of powertrain solutions for the most popular passenger car segments. http://www.punchpowertrain.com/en.

Caterpillar UK:
http://www.caterpillar.com/en/company/corp-overview/global-footprint/eame/uk.html

ABC Diesel: http://www.abcdiesel.be/en/index

Rype Office. offers three furniture options for customers: New, Remade or Refreshed, each appealing to different client preferences and openness to new business models and remanufactured products. http://www.rypeoffice.com

Trumetic Ltd (UK)*:* Trumetic Refrigeration Compressor Re-Manufacturing services offers a wide range of Refrigeration Compressor Servicing solutions for applications. http://www.trumeticlimited.co.uk/remanufacturing.php

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2.4.2. Co-design and open innovation with downstream partners to reduce environmental impact during product life cycle

Description

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 open 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 90).

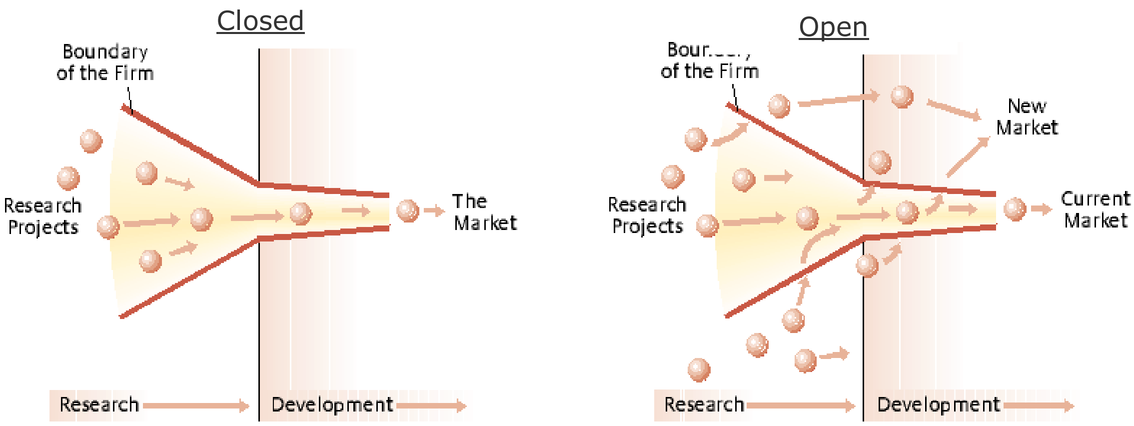

Figure 90. Closed vs. open innovation (Chesbrough, 2003)

Close 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. This 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. Open innovation also makes optimal use of available knowledge and expertise inside and outside the company.

Co-engineering, co-design and open innovation exist in a large variety of actions, i.e. from a single brainstorm session with limited number of stakeholders to a full process of designing, engineering, validation 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. 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 small firms (SME's) 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: Common in all cases is that the SMEs establish a network of external partners. Partners may be technology partners such as universities, research labs, or other companies, but in most cases these are not the most important partners in the network. The size of the network is determined by the type of products or services the SME wants to launch;
- Networks of partners have to be managed as well, but the type of management differs from the internal management of a firm. 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. The biggest challenge in an open innovation network is the market and technological risk on the one hand and the relational risk on the other hand. The glue of an open innovation network is the personal tie between a few key managers and actors;
- Dependence on partners' intellectual property (IP). Low-tech SMEs can rely on others' IP, or they co-develop technological innovations. Most often the small firms have negotiated technology agreements such as licensing deals with their partners;
- A stepwise approach. SMEs change their business model in a stepwise way. In most cases, companies begin with a (radically) new product or service, but this is only a start. There are several reasons why open innovation is a never-ending process for SMEs;
- 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.

Achieved environmental benefits

Co-design and open innovation in the Fabricated Metal Products sector provides the possibility to set up collaborations between small local SME's and large, globally operating companies. It will furthermore incentivize the Design for Environment (DfE) strategy by finding ways to create benefits for all involved partners while reducing the overall environmental impact. Achieved environmental benefits for the companies in the sector 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.

Appropriate environmental indicators

By the nature of the activity, co-design and open innovation acts on the companies (senior) management level. This means that key decisions can have major impacts on environmental impact and on economic impact. This makes clear the a generic environmental indicator measuring the impact of open innovation is impossible to define. On the other hand, the importance of environmental impact that the companies sets as part of their vision and strategy defines the potential impact.

Indicators for measuring performance of companies using co-design and open innovation depend on the production processes and materials, but in general this indicators give an overall view on how companies are doing:

- kg raw material used per produced unit;
- total energy use per produced unit;
- kg waste produced per year or per product;
- % of the products which complain to the quality standards.

A key indicator is to have a set of environmental impact goals set when co-design and open innovation is set up. Furthermore those goals can be translated to product requirements in close collaboration with the stakeholders. Often design requirements and features are trade-offs that can be evaluated using LCA. Depending on the product or service provided the environmental impact can be measured as resource or energy effectively (e.g. weight of resources used to provide specific functionality or service).

Cross-media effects

Efficiently controlling the open innovation process or the co-design process is a key factor to prevent overhead costs and efforts to offset the envisaged benefits.

Existing open innovation and co-design initiatives are not necessarily focussing on a reduction of the environmental footprint. The methods applied can in this case possibly lead to a higher environmental impact. Therefore, the focus and scope of the innovation process need to be controlled throughout the entire process in order to avoid negative cross-media effects.

Operational data

The operational condition largely depends on the size of the co-design or open innovation project. Below a few examples of existing co-design and open innovation processes in the sector are given.

Case study: 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.

ConXtech structures are manufactured in highly automated factories utilizing BIM, CAD/CAM, robotics, CNC machining and other technologies. Although these technologies have been employed in the automotive, aerospace and other industries for decades, the construction industry has been particularly slow to innovate or adopt technology for a variety of reasons. Now, as the world begins to recognize the value of building more sustainably, “technology” is the key to cost control and quality, and enables unprecedented efficiencies in the use of materials, time and energy in the built environment. 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).

Figure 91. The ConX® System (Cradle to Cradle Certified Products Registry, 2014)

Similar projects: Quicon, ATLSS, ConXtech and Girder Clamps.

Case study: General Electric (world)- Open innovation and micro-manufacturing
GE's original idea for open innovation and a micro-manufacturing facility came from the company's first crowdsourcing project to create a better jet engine bracket. In June 2013, the company held a contest in partnership with GrabCAD, an open engineering community called "3D printing design quest." GE released their original design for the titanium jet engine bracket and invited the public to riff off of it to create a lighter version that would be 3D printed. Over six weeks, more than 700 entries from 57 countries came in. The winner was a 21-year-old PhD student in Indonesia, who reduced the weight of the bracket by 84%. This case indicated not only that open innovation can work, but part of the reason why it works is thanks to the process of tapping into a very different group of people from the people who are normally thinking about the engineering challenges (TechRepublic, 2015).

Case study Curana (BE) - Design and innovation management
Curana is a worldwide trendsetter and manufacturer of extraordinary 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), 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.

Applicability

Since co-design and open innovation exists in a large variety of actions, it can be applied in both small and large companies in the Fabricated Metal Products sector. Crowdsource design contests can be a stepping stone to open innovation.

For SMEs this can illustrated by the Curana's approach, where different steps are applied (see operational data).

Economics

Setting up and coordinating the process of co-design and open innovation represent a cost, depending on the size of the actions. Furthermore, controlling the risks related to innovation during the entire processes has to be taken into account. The Business development and approaching new markets represent and additional cost as well.

Illustration of the economic impact of the open innovation at Curana is shown below (Figure 92).

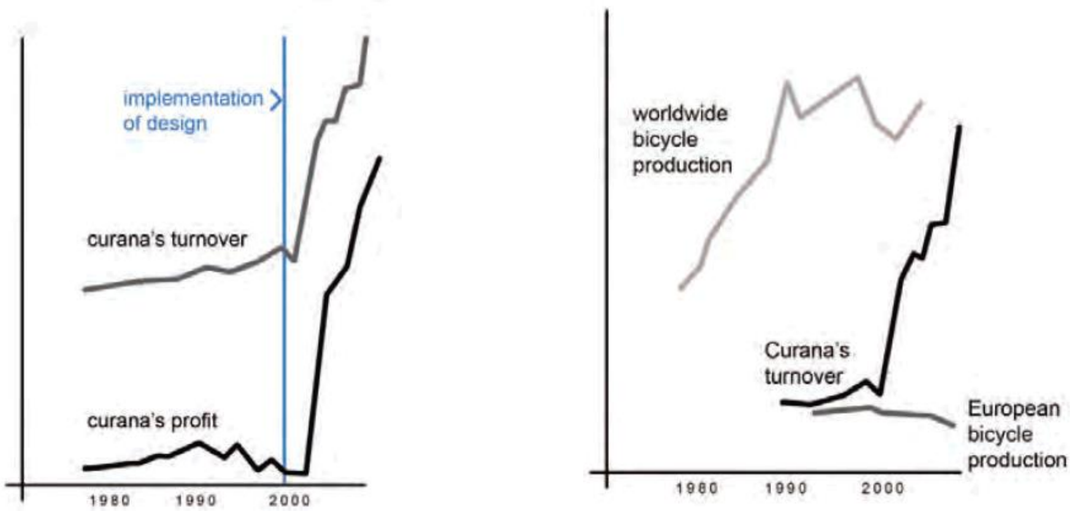

Figure 92: Curana's turnover and profit in relation to the bicycle production (Bosch, 2010)

Driving force for implementation

The main driving forces for implementing co-design or open innovation in the company in the Fabricated Metal Products sector are:

- Time to market reduction;
- Search for break-through innovations;
- Search for new strategic partnerships;
- Improvement of the market position through innovations;
- Increase of innovation capabilities of the company;
- Impact on the entire life cycle and environmental impact of a product.

Reference organizations

Holst Centre is an independent 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/).

ConXtech Inc. is a privately-held construction technology company in Pleasanton, CA. 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 the first Cradle to Cradle Certified steel building system in the world. (http://www.conxtech.com/company/history/).

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

Metal Valley. When it comes to design, engineering and production, we have to move with the changes in the market. This is why Metal Valley Netherlands offers partnerships with entrepreneurs, specialists and students. The only way to create new opportunities for the entire metal sector is through open innovation. (http://www.metalvalley.eu/en/innovation).

The 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).

Corda Campus. This is the leading tech campus in the heart of the EUREGIO. It is a motivating business community for countless innovative businesses and start-ups. Corda Campus is the place to be for fruitful partnerships and a fascinating exchange of knowledge and ideas. (http://www.cordacampus.com/nl/corda-campus/campus/corda-concept/open-innovatie).

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