INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO
MESTRADO EM ENGENHARIA MECÂNICA




GARRAFAS DE GÁS: UM ESTUDO COMPARATIVO ENTRE O USO DE AÇO E MATERIAIS COMPÓSITOS COM BASE NAS FERRAMENTAS DE ECO-DESIGN

PEDRO GIL SÁ LOPES PINTO RIBEIRO
novembro de 2018

POLITÉCNICO
DO PORTO

GAS CYLINDERS: A COMPARATIVE STUDY BETWEEN STEEL AND COMPOSITE MATERIALS BASED ON ECO-DESIGN TOOLS

Pedro Gil Sá Lopes Pinto Ribeiro

1160029

2018

Instituto Superior de Engenharia do Porto

Departamento de Engenharia Mecânica

POLITÉCNICO
DO PORTO

POLITÉCNICO
DO PORTO

GAS CYLINDERS: A COMPARATIVE STUDY BETWEEN STEEL AND COMPOSITE MATERIALS BASED ON ECO-DESIGN TOOLS

Pedro Gil Sá Lopes Pinto Ribeiro

1160029

Dissertation presented to the ISEP - School of Engineering, Polytechnic of Porto, to fulfil the requisites required to obtain a Master's degree in Mechanical Engineering, under the guidance of Professor Francisco José Gomes da Silva and Co-Supervision of Professor Arnaldo Manuel Guedes Pinto, Adjunct Professors at ISEP – School of Engineering, Polytechnic of Porto.

2018

ISEP - School of Engineering, Polytechnic of Porto

Department of Mechanical Engineering

POLITÉCNICO
DO PORTO

POLITÉCNICO
DO PORTO

JURY

President

Rui Pedro Cardoso da Silva Martinho, PhD

Adjunct Professor, ISEP - School of Engineering, Polytechnic of Porto

Supervisor

Francisco José Gomes da Silva, PhD

Adjunct Professor, ISEP - School of Engineering, Polytechnic of Porto

Co-Supervisor

Arnaldo Manuel Guedes Pinto, PhD

Adjunct Professor, ISEP - School of Engineering, Polytechnic of Porto

Examiner

Catarina Judite Morais Delgado Castelo Branco, PhD

Auxiliar Professor, Faculty of Economics, University of Porto

AGRADECIMENTOS

Aos meus pais, pelo permanente apoio e incentivo ao crescimento pessoal, académico e profissional.

Ao meu filho Tomás e em especial à minha esposa Juliana que, com sacrifício pessoal, me proporcionou todas as condições para me focar neste desafio.

Ao professor Francisco Silva, pela sua disponibilidade, exigência e profissionalismo desde o meu primeiro contacto.

Aos meus colegas de curso, que completaram o meu enriquecimento curricular, com novas amizades e aprendizagens.

À empresa Worthington Cylinders, SA e ao grupo Worthington Industries, pela filosofia de apoio e incentivo ao desenvolvimento pessoal dos seus colaboradores.

PALAVRAS CHAVE

Eco-design; implementação de LiDS Wheel; garrafas de gás em compósito;

RESUMO

Actualmente, as novas gerações dedicam uma maior atenção aos impactos nefastos de certos produtos na natureza. A seleção de produtos no momento da compra torna-se mais criteriosa, e se não pelo dever de cidadania, as empresas vêm-se forçadas a adaptar a sua realidade à procura dos consumidores, com produtos e processos mais amigos do ambiente.

A sustentabilidade é o ponto de partida e de chegada de várias políticas e modelos desenvolvidos, para assegurar que o consumo de recursos de hoje, não comprometa a sua disponibilidade no futuro. Assim, diversos modelos foram desenvolvidos para impor e guiar os agentes económicos a prosseguir com uma filosofia que não assente apenas no consumo desmesurado, mas sim racional e responsável.

No âmbito destes modelos, surge a necessidade de assegurar que os ciclos de vida dos produtos tenham um impacto reduzido. Para tal, o processo deve começar no desenvolvimento inicial do produto. O Eco-design, vem introduzir metodologias de avaliação de impacto do produto, desde a sua produção, tempo de vida e reciclagem.

Neste trabalho, selecionou-se um produto existente há muitos anos no dia a dia das populações – garrafa de gás residencial em aço - e um produto substituto desenvolvido recentemente tendo em consideração as preocupações do ciclo de vida do produto, no ambiente – garrafa de gás residencial em compósito e aço.

Para avaliar a efectiva evolução na passagem de um modelo tradicional, para um produto inovador e bem aceite pelo consumidor, implementou-se uma ferramenta de avaliação de Eco-design – LiDS Wheel.

Durante o processo de implementação da ferramenta na análise dos dois modelos, procurou-se analisar os critérios de análise das principais estratégias de Eco-design. Para tal, fez-se uma pesquisa sobre as características do produto final, mas também dos seus materiais e processos de produção.

Os resultados obtidos permitem não só obter uma percepção das vantagens e desvantagens entre os 2 modelos, mas também perceber quais são as estratégias que ainda devem ser melhoradas em cada opção. Ou seja, a ferramenta serve igualmente de orientação para a melhoria dos actuais modelos, ou no desenvolvimento de produtos inovadores.

KEYWORDS

Eco-design; LiDS Wheel implementation; composite gas cylinders;

ABSTRACT

At present, the new generations are imposing more attention on the harmful impacts of certain products to the environment. The product selection in the purchasing moment, becomes more judicious, and if not for the duty of citizenship, companies are forced to adapt their reality to the consumers' preferences, with products and processes more environmentally friendly.

Sustainability is the point of departure and arrival of various policies and models developed to ensure that today's resource consumption does not compromise its availability in the future. Thus, several models have been developed to impose and guide economic agents to pursue a philosophy that is not based only on excessive consumption, but rational choices and responsibility.

Within these models, there is a need to ensure that the product lifecycle has a reduced impact. To be more effective, the process must begin during the initial product development. Eco-design introduces methodologies to evaluate the impact of the product, from its production, lifetime until the very end of product life.

In this work, was chosen a product that exists for many years in the day-to-day life of the populations - residential steel gas cylinder - and a recently developed substitute product – residential composite and steel cylinder – where the product development has considered the lifecycle concerns, from the conception phase until the recycling stage.

To evaluate the effective evolution in the passage from the traditional model, to an innovative product and well accepted by the consumer, an evaluation tool of Eco-design - LiDS Wheel was implemented.

During the implementation process of the tool, to analyse the two models, was necessary to answer the criteria that define each of the main strategies of Eco-design. For this, research was done on the characteristics of the final product, but also on its materials and production processes.

The results obtained, not only allows a perception of the advantages and disadvantages of the two models but also realize which are the strategies that still must be improved on each model. In other words, the tool also serves as a guide for the improvement of current models, or for the development of innovative products.

LIST OF SYMBOLS, ABBREVIATIONS AND UNITS

List of Abbreviations

AA	AMTROL-ALFA company
ADR	European Agreement - International Carriage of Dangerous Goods by Road
CAD	Computer-Aided Drawing
CAE	Computer Aided Engineering
CE	European Conformity
DD	Disassembly, Disposal
DfE	Design for Environment
DOT	Department of Transport
EEC	European Economic Community
ELU	Environmental Load Units
EPS	Environmental Priority Strategies
EMS	Environmental Management System
ESR	Essentially Safety Requirements
GDP	Gross Domestic Product
GMAW	Gas Metal Arc Welding
GNP	Gross national product
HDI	Human Development Index
HDPE	High-Density Polyethylene
IAEA	Inter-Agency and Expert Group
IMDG	International Maritime Dangerous Goods
ISO	International Standards Organization
LCA	Life Cycle Assessment
LCT	Life Cycle Thinking
LiDS	Lifecycle Design Strategies
LPG	Liquefied Petroleum Gas
MDGs	Millennium Development Goals
MET	Materials, Energy and Toxicity
MPD	Marketing, Planning, Development

MTBF	Mean Time Between Failures
PM	Procurement, Manufacture
SCM	Supply Chain Management
SDGs	Sustainable Development Goals
SUN	Sustainable United Nations
TPED	Transportable Pressure Equipment Directive
UA	Use, Application
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
WT	Washing Tanks

List of units

T	Tons
W	Watt
K	Kelvin
°C	Celsius
mm	Millimetre
L	Litre
kW	Kilowatt
m^3	Cubic meter
MBTU/ton	One Million British Thermal Units
mg	Milligram
mg/Nm^3	Milligrams per Normal cubic meter
mgC/Nm^3	Milligrams of Carbon per Normal cubic meter

List of symbols

%	Percentage
CO_2	Carbon dioxide
NOx	Nitrogen Oxide
VOC's	Volatile Organic Compounds

\$	Dollar
Π	Pi-mark

GLOSSARY OF TERMS

COMET®	Brand stands for COMposite + METal.
Composite cylinder	The term composite is used mostly of the times to refer to cylinders made of both, steel and composite.
Jacket	Term is used to define the outer part of the composite cylinders.
Software	Sequence of written instructions to be interpreted by a computer, with the purpose of performing specific tasks.
State of the art	The term refers to best practices applied.
Steel cylinders	The term steel cylinders are used to refer to steel-only type of cylinder.

LIST OF FIGURES

FIGURE 1 - SUSTAINABLE DEVELOPMENT [6] 36
FIGURE 2 - A TYPICAL PRODUCT LIFECYCLE DIAGRAM [13] 38
FIGURE 3 - 17 SUSTAINABLE DEVELOPMENT GOALS (SDGS) [23] 41
FIGURE 4 – THREE DIMENSIONS OF SUSTAINABLE DEVELOPMENT GOALS (SDGS) [25] 42
FIGURE 5 - INITIAL APPROACH TO PRODUCT LIFECYCLE[33] 45
FIGURE 6 - RELATIONSHIP BETWEEN ISO 14001, ISO 9001, ISO 19991 AND ISO 14006 [42] 46
FIGURE 7 - OVERVIEW OF GENERIC TOOLS CONCERNING ENVIRONMENTAL MANAGEMENT [47] 48
FIGURE 8 – ECO-DESIGN METHODOLOGY FLOWCHART [42], [50] 49
FIGURE 9 – MAIN REQUIREMENTS FROM ISO14001 AND ISO 14006 [53] 51
FIGURE 10 – MAIN QUALITATIVE DESIGN TOOLS [53] 52
FIGURE 11 – EXAMPLES OF OTHER QUALITATIVE DESIGN TOOLS 53
FIGURE 12 – LIFE CYCLE ASSESSMENT ILLUSTRATION [66] 54
FIGURE 13 - LIDS WHEEL ADAPTED FROM [72], [73] 56
FIGURE 14 - ECO-DESIGN CHECKLIST [73] 58
FIGURE 15 - EXAMPLES OF INPUT OF RULES INTO THE DEVELOPMENT PHASE 60
FIGURE 16 – IMPROVEMENT CHART 60
FIGURE 17 – SIZE RANGE OF HIGH PRESSURE GAS CYLINDERS AVAILABLE [83] 63
FIGURE 18 – SIZE RANGE OF LOW PRESSURE GAS CYLINDERS AVAILABLE [83] 64
FIGURE 19 – SIZE RANGE OF ACETYLENE CYLINDERS AVAILABLE [83] 64
FIGURE 20 – MAIN COMPONENTS OF A STEEL PRESSURE CYLINDER [93] 68
FIGURE 21 - LPG STEEL CYLINDER PRODUCTION FLOW 69
FIGURE 22 – COMPONENTS OF THE COMET® CYLINDER [94] 71
FIGURE 23 – COMET® PRODUCT RANGE [95] 71
FIGURE 24 - COMPOSITE CYLINDER CONSTRUCTION COMET® [95] 72
FIGURE 25 - THE THERMOPLASTIC WINDING MACHINE [93] 72
FIGURE 26 - LPG COMPOSITE CYLINDER PRODUCTION FLOW 73
FIGURE 27 - POLYMERIC COAT ON COMET CYLINDER [93] 88
FIGURE 28 - CIRCUMFERENTIAL WELDING PROCESS - SUBMERGED ARC WELDING [93] 92
FIGURE 29 – PAINTING LINE 93
FIGURE 30 - LIDS WHEEL COMPARING STEEL AND COMPOSITE RESULTS 102

FIGURE 31 – ELU - ENVIRONMENTAL LOAD UNIT OF DIFFERENT MATERIAL CYLINDERS [94] 103

FIGURE 32 - EXAMPLES OF ECO-DESIGN TECHNIQUES AND TOOLS [110] 121

FIGURE 33 – ECO-DESIGN STRATEGIES ACROSS THE LIFECYCLE OF THE PRODUCT 122

FIGURE 34 - LPG STEEL CYLINDERS REQUALIFICATION WITHIN EU/CEN COUNTRIES (ADR) [87] 123

FIGURE 35 - LPG COMPOSITE CYLINDERS REQUALIFICATION PERIOD [108]...124

LIST OF TABLES

TABLE 1 - COMET 24L [95] 79
TABLE 2 - LPG STEEL CYLINDER 26,2L [95] 79
TABLE 3 - DEMATERIALIZATION CRITERIA EVALUATION 81
TABLE 4 - SHARED OF PRODUCT CRITERIA EVALUATION 81
TABLE 5 - INTEGRATION OF FUNCTIONS CRITERIA EVALUATION 81
TABLE 6 - FUNCTIONAL OPTIMIZATION OF PRODUCT/COMPONENT CRITERIA EVALUATION 82
TABLE 7 - MATERIALS AND CONSUMABLES USED DURING PRODUCTION [93] 82
TABLE 8 - CLEANER MATERIALS CRITERIA EVALUATION 83
TABLE 9 - RENEWABLE MATERIALS CRITERIA EVALUATION 83
TABLE 10 - MATERIALS AND ENERGY REQUIRED FOR CYLINDER CONSTRUCTION [93], [94] 83
TABLE 11 - LOWER ENERGY CONTENT MATERIALS CRITERIA EVALUATION 84
TABLE 12 - RECYCLED MATERIALS CRITERIA EVALUATION 84
TABLE 13 - MATERIALS AND CONSUMABLES USED IN STEEL CYLINDERS CONSTRUCTION [93] 84
TABLE 14 - MATERIALS USED IN COMPOSITE CYLINDERS CONSTRUCTION [93] 85
TABLE 15 - RECYCLABLE MATERIALS CRITERIA EVALUATION 85
TABLE 16 - MATERIALS WEIGHT PER MODEL [93] 86
TABLE 17 - REDUCTION IN WEIGHT CRITERIA EVALUATION 86
TABLE 18 - STEEL AND COMPOSITE CYLINDERS DIMENSIONS [95] 87
TABLE 19 - REDUCTION IN VOLUME CRITERIA EVALUATION 87
TABLE 20 - ALTERNATIVE PRODUCTION TECHNIQUES CRITERIA EVALUATION 88
TABLE 21 - FEWER PRODUCTION TECHNIQUES CRITERIA EVALUATION 89
TABLE 22 - ENERGETIC CONSUMPTION, PER MODEL TYPE [93] 89
TABLE 23 - LOWER AND CLEANER ENERGY CONSUMPTION CRITERIA EVALUATION 89
TABLE 24 - MATERIALS USED AND DISPOSED ON MODELS' PRODUCTION [93] 90
TABLE 25 - LESS PRODUCTION WASTES CRITERIA EVALUATION 90
TABLE 26 - INDUSTRIAL EFFLUENTS, PER MODEL TYPE [93] 90
TABLE 27 - GASEOUS EMISSIONS ON WASHING TANKS PER MODEL TYPE [93] 91
TABLE 28 - GAS EMISSIONS ON WELDING PROCESS, PER MODEL TYPE [93] 91
TABLE 29 - GAS EMISSIONS FROM PAINTING LINE - STEEL CYLINDER [93] 92
TABLE 30 - GASEOUS EMISSIONS FROM AN EXHAUST SYSTEM OF CURE OVEN, PER MODEL TYPE [93] 93

TABLE 31 - GASEOUS EMISSIONS FROM BURNERS OF CURE OVEN, PER MODEL TYPE [93] 93
TABLE 32 - GAS EMISSIONS FROM SHOT STEEL EQUIPMENT - STEEL CYLINDERS [93] 93
TABLE 33 - GASEOUS EMISSIONS FROM HEATING TREATMENT EQUIPMENT - STEEL CYLINDERS [93] 94
TABLE 34 - FEWER/CLEANER PRODUCTION CONSUMABLES CRITERIA EVALUATION 94
TABLE 35 - LESS/CLEANER/REUSABLE PACKAGING CRITERIA EVALUATION 94
TABLE 36 - ENERGY EFFICIENT TRANSPORT MODE CRITERIA EVALUATION 94
TABLE 37 - LOGISTIC INFORMATION, BY MODEL TYPE [93] 95
TABLE 38 - ENERGY EFFICIENT LOGISTICS CRITERIA EVALUATION 95
TABLE 39 - LOWER ENERGY CONSUMPTION CRITERIA EVALUATION 96
TABLE 40 - CLEANER ENERGY SOURCE CRITERIA EVALUATION 96
TABLE 41 - CLEANER CONSUMABLES CRITERIA EVALUATION 96
TABLE 42 - NO WASTE OF ENERGY/CONSUMABLES CRITERIA EVALUATION 97
TABLE 43 - RELIABILITY AND DURABILITY CRITERIA EVALUATION 97
TABLE 44 - EASIER MAINTENANCE AND REPAIR CRITERIA EVALUATION 97
TABLE 45 - MODULAR PRODUCTS STRUCTURE CRITERIA EVALUATION 98
TABLE 46 - CLASSIC DESIGN CRITERIA EVALUATION 98
TABLE 47 - STRONG PRODUCT-USER RELATION CRITERIA EVALUATION 98
TABLE 48 - RE-USE OF PRODUCT CRITERIA EVALUATION 99
TABLE 49 - REMANUFACTURING/REFURBISHING CRITERIA EVALUATION 99
TABLE 50 - END-LIFE MATERIALS TO RECYCLE, BY MODEL TYPE [93] 99
TABLE 51 - RECYCLING OF MATERIALS CRITERIA EVALUATION 100
TABLE 52 - MATERIALS USED IN CYLINDER, FOR INCINERATION [93] 100
TABLE 53 - SAFER INCINERATION CRITERIA EVALUATION 100
TABLE 54 - LIDS WHEEL DETAILED EVALUATION 100
TABLE 55 - RESULTS OF THE AVERAGE EVALUATION OF CRITERIA ON EACH STRATEGY 101
TABLE 56 - IMPROVEMENTS ACHIEVED 108

TABLE OF CONTENTS

1 INTRODUCTION ... 29
1.1 Contextualization ... 29
1.2 Main goals ... 29
1.3 Dissertations methodology ... 30
1.4 Dissertation's structure ... 31
1.5 Welcoming company ... 31
2 LITERATURE REVIEW ... 35
2.1 Sustainability ... 35
2.1.1 Main principles ... 35
2.1.2 Economic concerns ... 38
2.1.3 Environmental concerns ... 38
2.1.4 Social concerns ... 39
2.1.5 Factors influencing sustainability ... 39
2.1.6 Sustainability goals & tools ... 41
2.2 Eco-Design ... 44
2.2.1 Main Principles ... 46
2.2.2 Eco-design within a comprehensive Environmental Management analysis ... 47
2.2.3 Eco-design Tools ... 51
2.2.3.1 Quantitative Design Tools ... 52
2.2.3.2 Qualitative Design Tools ... 52
2.2.4 Main tools Application ... 53
2.2.4.1 Life Cycle Assessment ... 53
2.2.4.2 Life Cycle Design Strategy Wheel ... 56
2.2.4.3 Eco-design Checklists ... 57
2.2.5 Recent developments and future trends ... 58
2.2.6 Case-studies ... 59
2.3 Pressure cylinders ... 62
2.3.1 Business ... 62
2.3.2 Pressure cylinder types ... 64
2.3.3 Product requirements ... 65
2.3.4 Regulations ... 67
2.3.5 Steel cylinders ... 67
2.3.5.1 Production flow ... 68
2.3.5.2 Main processes ... 70
2.3.6 Composite cylinders ... 71
2.3.6.1 Production flow ... 72
2.3.6.2 Main processes ... 74
2.3.7 Logistics ... 74
2.3.7.1 Packaging ... 74
2.3.7.2 Restrictions ... 74
2.3.7.3 Optimization versus transportation restrictions ... 75
3 DEVELOPMENT ... 79

3.1 Case study 79
3.2 Eco-design tool selection....80
3.3 LiDS wheel model implementation 80
3.3.1 New concept development....80
3.3.1.1 Dematerialization....81
3.3.1.2 Shared use of the product....81
3.3.1.3 Integration of functions 81
3.3.1.4 Functional optimization of product/components....82
3.3.2 Selection of low-impact materials 82
3.3.2.1 Cleaner materials 82
3.3.2.2 Renewable materials....83
3.3.2.3 Lower energy content materials 83
3.3.2.4 Recycled materials 84
3.3.2.5 Recyclable materials....84
3.3.3 Reduction of material usage 86
3.3.3.1 Reduction in weight 86
3.3.3.2 Reduction in volume 87
3.3.4 Optimization of production techniques....87
3.3.4.1 Alternative production techniques 87
3.3.4.2 Fewer production steps 88
3.3.4.3 Lower and cleaner energy consumption....89
3.3.4.4 Less production wastes 89
3.3.4.5 Fewer/cleaner production consumables 90
3.3.5 Optimization of distribution system 94
3.3.5.1 Less/cleaner/reusable packaging....94
3.3.5.2 Energy efficient transport mode 94
3.3.5.3 Energy efficient logistics....95
3.3.6 Reduction of impact during use....95
3.3.6.1 Lower energy consumption....96
3.3.6.2 Cleaner energy source....96
3.3.6.3 Cleaner consumables 96
3.3.6.4 No waste of energy/consumables....96
3.3.7 Optimization of initial lifetime....97
3.3.7.1 Reliability and durability....97
3.3.7.2 Easier maintenance and repair 97
3.3.7.3 Modular product structure 97
3.3.7.4 Classic design....98
3.3.7.5 Strong product-user relation....98
3.3.8 Optimization of end of life system....99
3.3.8.1 Re-use of product....99
3.3.8.2 Remanufacturing/refurbishing....99
3.3.8.3 Recycling of materials 99
3.3.8.4 Safer incineration....100
3.4 LiDS Wheel model results....100
3.5 Results Interpretation 102
3.6 Results validation 103
4 CONCLUSIONS 107
4.1 Main conclusions....107

4.2 Personal outcomes 108
4.3 Suggestions for future researches 108
5 BIBLIOGRAPHY AND OTHER RESOURCES 111
6 ANNEXES 121
6.1 ANNEX I 121
6.2 ANNEX II 122
6.3 ANNEX III 123
6.4 ANNEX IV 124

INTRODUCTION

1.1 CONTEXTUALIZATION
1.2 MAIN GOALS
1.3 DISSERTATION’S METHODOLOGY
1.4 DISSERTATION’S STRUCTURE
1.5 WELCOMING COMPANY

1 INTRODUCTION

1.1 Contextualization

A new level of consciousness is rising, developing an ecological mindset in the new generations. The climatic changes, effects on biodiversity and negative impact on the future of human nature, has motivated a strong investment in education during the last decades, trying to change behaviours from within, adapting needs to planet capacity.

World societies still define their survival based on economic sustainability, pressured by worldwide competition. Some decisions can be positive in a short or medium-term basis but compromising irreversibly the society general welfare.

The United Nations (UN) organization, on its main competence of global authority, has been conducting a worldwide guide to sustainability. Opposing to free-market and short-term inconsequent decisions, UN has imposed phased goals conducting countries to implement gradually hard changes in their economy (Sakr *et al.*, 2017).

A new generation of consumers is now changing the demand paradigm. The product choice is moving from single price-oriented decision to a value-for-money decision. The “value” is more and more considering also the environmental impact of the product during its life-cycle (Taylor, 2006).

The present analysis intends to use eco-design tools, to prove whether a switch from a classic steel cylinder to a new technology and composite cylinder, generates benefits for the environment.

1.2 Main goals

This work intends to prove, using eco-design tools, if the new technology brought from the composite cylinders has a positive effect on environmental impact when compared to the traditional steel-only cylinders. The selected models for analysis, are the ones traditionally used for Liquefied Petroleum Gas (LPG). The main goals for this analysis are:

- To collect both models’ information about materials, production, use, logistic and recycling.
- Define and implement an Eco-design model to evaluate both types performance
- Analyse results, and identify main differentiating points
- Validate results with other similar studies, using different methods
- Conclude about environmental impact of both models

1.3 Dissertation's methodology

The methodology to be used building up this dissertation will obey to a sequential explanation of the approached concepts, through a literature review. Starting with the general meaning of sustainability, the analysis will focus on the eco-design concept, describing principles and tools to be used.

The products to be studied are within the pressure cylinders sector. Therefore, a framework of the business will be described to understand the potential and limitations of the business.

After the themes are clear, an eco-design tool will be applied, to study two selected models. The interpretation of the results will allow us to conclude whether the innovation brought advantages from the environmental point of view.

1. Research about Sustainability concepts and approach on Economic, Social and Environmental perspective.
2. Eco-design main principles analysis, tools and application.
3. Pressure cylinders business, requirements and regulation framwork.
4. Steel cylinders production flow and processes description.
5. Composite cylinders production flow and processes description.
6. Anaylises on the packaging and logistic issues.
7. Definition of an Eco-design method to analyse impact of a selected steel cylinder and a composite type.
8. Model implementation and assessment.
9. Results analysis and conclusions.

1.4 Dissertation's structure

The first chapter makes a presentation of the work being developed, the context on which it is made and the goals that are intended to be pursued. The chapter also includes the methodology as well as the document structure. The manufacturing company referred in this work is also presented, as their contribution.

The second chapter starts with a literature review on sustainability, which is the basis of the whole concept, from an economic, social and environmental perspective. Within the sustainability tools, the workflow focuses on the eco-design approach, describing its principles, contextualization, tools and application. The products, focus of the study, are also described in this chapter, making first a business analysis, and passing through the production flow and processes used. The packaging and logistic limitations are also overviewed briefly, indicating the sector and regulatory limitations.

The third chapter intends to be the model implementation applied to the two different products selected. Model is implemented with the product assessment through the criteria defined by the method. Results are systematized and compared with similar works, using different models, to sustain model accuracy.

The fourth chapter passes through the data, to get into a conclusion with the obtained results. Some suggestions are made for future works, around this products and sector.

In the fifth chapter, the bibliography used as a basis to this work is summarized sequentially.

The six chapter has some annexes to this work, where some relevant documentation is attached for a better understanding of its content.

1.5 Welcoming company

The models studied in this project were developed and manufactured in the company AMTROL-ALFA, located in Guimarães, Portugal.

AMTROL-ALFA (AA) was founded in 1962 and passed through many product re-engineering processes over the years. It started with the production of Liquefied-fuels pumps. The transition to the actual facilities in 1966, marked the beginning of the production of cylinders to Liquefied Petroleum Gases (LPG).

Since the foundation, several acquisitions and changes occurred within the company. Those changes deeply marked the company philosophy, preparing it to face new starts. This preparation may be the main reason why AA is today one of the leading companies in its sector, being a reference on innovation.

AMTROL-ALFA was acquired by WORTHINGTON INDUSTRIES in June 2017. The in-house knowledge, market position and innovation capacity were the main reasons for the acquisition, making AA an important asset to any group that looks toward worldwide market leadership.

LITERATURE REVIEW

2.1 SUSTAINABILITY
2.2 ECO-DESIGN
2.3 PRESSURE CYLINDERS

2 LITERATURE REVIEW

2.1 Sustainability

Sustainability refers to an equilibrium of several factors. The sustainable development concept emerged from environmental movements together with science approaches, during the 70's and 80's of the nineteen-century (Porrini *et al.*, 2017). The rationale behind sustainable development involves a large range of topics that could turn very difficult to detail. Anyway, a comprehensive definition of sustainable development can define it, as a "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Stellwagen *et al.*, 1975). The Sustainable development is stated as an assumption and guideline for development (General Assembly of the United Nations, 2018).This concept defines the paradigm that will guideline and justify the research made on this report.

The first idea of development was the capacity to transform societies in modern mass-consumption realities. Based on this assumption, some friction occurred between the efforts to promote economic growth and the measures to assure basic needs support. This development paradigm has caused a negative impact at the environmental level. A sustainable approach must guaranty social equilibrium and limited environmental impact accordingly to the needs to sustain a solid economy. To assure equity between generations and economic growth is mandatory that natural capital must be conserved. The market by itself is not able to be effective on conservation, but instead, it forces a degradation trend of that natural capital. The social perspective, requires equity, basic health and education needs to be assured, as well as a fair and active participation of the population in the democratic process; these are signs and requirements for sustained development (Giovannoni *et al.*, 2013; Jeronen, 2013; Khalili *et al.*, 2015).

The United Nations Environment Programme (UNEP) is the official entity, named by the United Nations (UN), to lead the environmental global orientation. The UNEP has the responsibility to define guidelines for the world countries and authorities, on environmental issues, supporting them with best practices and policies. Global experiences and initiatives are shared by the UN members, using for the effect a communication programmed ran by the "Greening the Blue" initiative, supported by the UN (General Assembly of the United Nations, 2018).

2.1.1 Main principles

The first principle of sustainable development integrates the three major pillars such as Economic, Environmental and Social. Coordinated strategy between these three pillars is mandatory to a sustainable growth. On the economic side, a sustainable system must "be able to produce goods and services on a continuing basis, to maintain manageable levels of government and external debt, and to avoid extreme sectoral imbalances which damage agricultural or industrial production (Jeronen, 2013). The Social perspective for sustainable development considers that a sustainable system requires equity on distribution, provide social support like education and health system, gender equity and people participation in governance. From the environmental perspective, a sustainable system must assure a rational and stable resource use. The use of renewable and non-renewable resources should be limited to the strictly necessary, when not possible to use adequate substitutes. Also, these resources use rate should be in line and limited to the same rate of alternatives creation and dedicated policies to maintain biodiversity, the stability of the atmosphere, as well as other ecosystem functions (Jeronen, 2013). The Figure 1 represents the matrix of the environmental, social and economic pillars, and their intersection relevance, from where we can reach the ambitioned sustainable development.

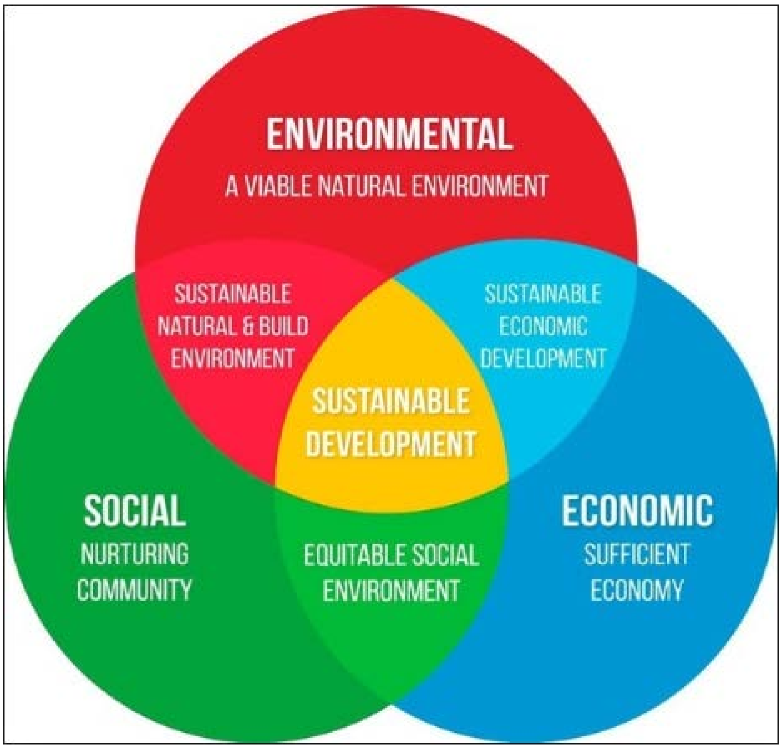

Figure 1 - Sustainable development [6]

The second principle enhances the generational heritage. The long-term effects of nowadays' decisions should be considered, balancing between the what is a short decision and a long-term decision. To evaluate such decisions, a correct evaluation should be made, considering the risks for the upcoming generations in order to mitigate them, as well as to build a plan to meet next generation's needs. Both second and first principles have been referred within a perspective where sustainability implies an equilibrium between environmental, social and economic aspects, together with short and long-term landscape (Milojevic *et al.*, 2008; Muñoz-Torres *et al.*, 2018).

The third principle for sustainable development assumes the involvement of persons or entities, affected by any sustainability impact, the traditionally called stakeholders. The sustainable development identifies the needs of not only the current society but also the ones of future generations. Those identified needs affect different types of stakeholders, which may cause some conflict of interest. Basically, what can benefit some groups, can strongly affect current or future stakeholders. From the corporate and organizational point of view, organizations must consider the different expectations or needs from different stakeholders, that may have consequences on the organization outcome. From the other side, if one think from supply chain perspective, focusing not on the outcome from the organization, but from the set of interests where the organization operates, it is mandatory to manage the relationship with customers, suppliers, authorities, services, and all others involved or impacted by any implemented policy. To get the stakeholders involved and understand their needs, is necessary to engage them on such efforts (Bal *et al.*, 2013; Muñoz-Torres, 2018).

The fourth principle focuses the attention to Life Cycle Thinking (LCT). The LCT goes further than just thinking the traditional production plan and manufacturing process, to introduce worries on the social, economic and environmental consequences of a certain product, from the early stage until their end-life. The key goal of LCT is to minimize the unnecessary use of resources and negative emissions to the environment of a product but keeping the improvement of its performance from a social and economic perspective, during product lifecycle time. Gathering all these worries on an early stage may help to balance the key factors of social, environmental and economic effects within an organization, through the entire product value-chain (Schöggl *et al.*, 2017). If one looks at the industrial sector as of major importance for this topic, the Life Cycle Thinking approach goes beyond the shop floor improvements. The LCT starts with the product design and concept to the raw materials origin and the energetic impact. The selection of what materials to use and the expected energy consumption are part of the manufacture process and packaging, logistic, consumer use, assistance, recycling process, re-use and eventual recovery or final product disposal. On each lifecycle stage, there is room to accommodate such policies to minimize resources consumption, without compromising or even improve the product performance (Chistilin, 2010; United Nations Environment Programme, 2012). The Figure 2 represents a product lifecycle, starting from the resources used, until the final step of incineration or landfilling.

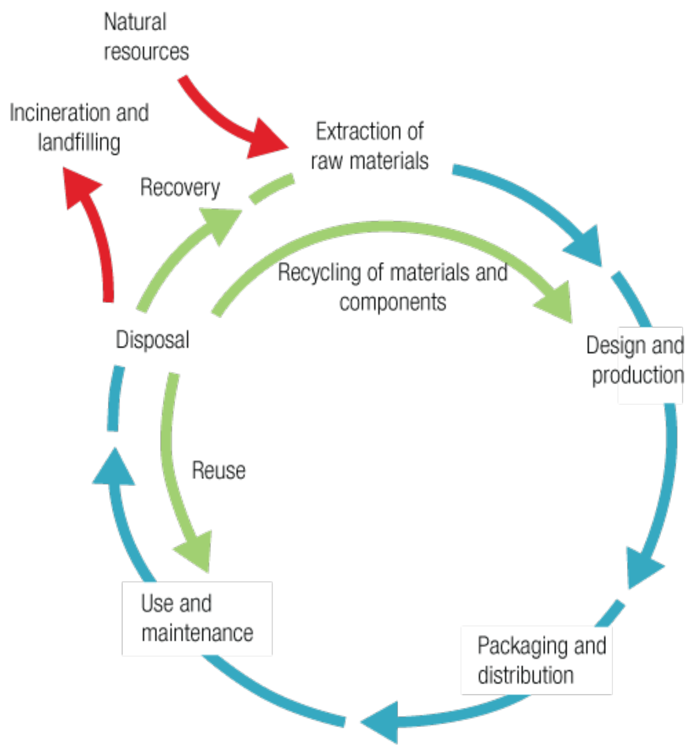

Figure 2 - A typical product lifecycle diagram (United Nations Environment Programme, 2012)

2.1.2 Economic concerns

The Economic pillar, from a theorist neo-classical view, has defined sustainability only based on consumer needs' satisfaction. To sustain this demand, goods and services must be produced on a permanent basis. This sustainability view would be driving financially healthy and dynamic economies (Basiago, 1999).

Anyway, going along the years and going deeper on the economic perspective of sustainability, the finite resources management enter the equation. Raw materials and energy have a strong impact on costs and at the same time, globalization brings price pressure and a growing conscience from consumers to select green companies. The efficient resource allocation became the focus to achieve, not only costs reduction, but to assure an economic sustainability (Jeronen, 2013),(Pernot *et al.*, 1978).

2.1.3 Environmental concerns

In line to the increasing consciousness of limited resources, together with the negative impact on people wellbeing in the last couple of decades, environmental concerns became the focus of discussion. From one side, is a fact that fields are being intensively used in an uncontrolled agriculture. By the other side, cities are over occupied by persons, cars, industries etc.; and the resources-use gap between industrialized countries and developed nations is increasing. Despite this consciousness, the industrial lobby has all the conditions to continuously format the regulation accordingly to their interests and limiting any control efforts. Over the last decades, a relevant part of natural resources was significantly abused. To put a hand on this trend, it will be challenging, and it is one of the most difficult obstacles to overcome when working towards sustainability (Goosen, 2012; Jeronen, 2013).

2.1.4 Social concerns

A relevant concern is the need to assure equity in development, as reported by the United Nations Development Programme's series of Human Development Reports. To calculate HDI (Human Development Index), which measures the success of development based on per capita GNP (Gross National Product) or GDP27 (Gross Domestic Product), the Human Development Reports drives the attention to an additional aspect other than social and economic development, which is the democratic governance, poverty and inequity on gender (Lee, 2011).

The Human Development Index results from the combination of several aspects such as adult literacy, school enrolment, life expectancy, that together with per capita GDP will result in a ration average between 0 and 1. The rationale behind this calculation is to show how complex the development analysis can be, in a way that cannot just be the result of high GDP rates.

Many countries are the evidence of such a statement, where high GDP gaps with HDI, are contrasting with other countries precisely in the opposite situation. It is also a fact that HDI is not including, in a clear way, the environmental aspect, although the report from 1994 has discussed the sustainability and equity relation, in the following way: "*The concept of sustainable development raises the issue of whether present lifestyles are acceptable and whether there is any reason to pass them on to the next generation. Because intergenerational equity must go hand in hand with intragenerational equity, a major restructuring of the world's income and consumption patterns may be a necessary precondition for any viable strategy of sustainable development... Development patterns that perpetuate today's inequities are neither sustainable nor worth sustaining*" (Jeronen, 2013).

Summarizing, the social pillar must assure the following aspects (Koroneos *et al.*, 2012):

- Assure the human values of justice, peace, democracy, rule and solidarity;
- Assumes the need to protect nature, that integrates all people and their cultures as a single part, making this requirement a basis for policies and actions, locally as globally;
- The economic, political and cultural aspects from different regions should not be ignored, but considered, to define a pace;
- Technology would be a part and supporting tool.
- All these aspects lead us to reinforce what a social development cannot be (Koroneos, 2012):
- A limited goal to "developed" countries or dedicated to specific social classes;
- Aligned to the increasing and accentuated social inequalities between countries, or between social classes.

2.1.5 Factors influencing sustainability

When looking for a sustainable development definition, some extreme positions can be easily found, but with very negative impacts. One of the extremes, is the already mentioned neoclassical view of a successful and sustainable society, by measuring it by their consumption capacity. This perspective assumes a continuous growth to satisfy permanent and increasing demand from society, reducing or ignoring the sociological and ecologic aspects. The restricted focus on consumption, and therefore, production, seems an easy target to achieve by increasing their capacity. Anyway, the price to achieve it may result in high costs for the society by destroying ecosystems, free-market driven by economic interests and by consequence, social equity and political decisions may be wrongly influenced. The other extreme position is to base our sustainable development definition, by only focusing on ecological and social issues, ignoring the need to create conditions for economic growth. It is commonly accepted that education, gender equity, health, true democracy, peace etc., are essential to define as a sustainable society (Jeronen, 2013).

But how can these aspects be measured, quantified and balanced, together with the negative impacts on the social and environmental side, brought from the necessary production, to sustain the same society? The midpoint and more difficult to achieve, would be to find a decent balance between the essential consumption needs and the available resources (Weinberger *et al.*, 2015). Considering all the concerns described before on economy, social aspects and environmental impacts – some factors can be enhanced as a result of the impact of any reinforcement from an aspect into the other (Sugawara *et al.*, 2014):

• **Agriculture**: this sector is strongly representative of the duality of perspectives that can be implemented to assure sustainable development. A population with high levels of consumption requires an intensive use of the soils. From one side, production can be increased by using soils intensively with specific techniques, driving soil degradation and pollution. This trend requires the move into organic soils, diseases control and optimized water use. From the other side, the consumption should be adapted considering population growth, higher efficiency on food distribution by all regions, together with the assumed limited resources on production;

• **Energy**: Energy can be a good indicator to measure a society dynamic and political choices. The limited supply capacity and the environmental impact require new and cleaner sources to sustain high population needs. A transition from fossil fuels to non-fossil energy solutions is mandatory. To turn the biomass, solar and wind an advantage, it will require a strong and dedicated investment to extract its potentiality;

• **Industry**: With the strong increase of the industrial production to satisfy population consumption, the ecological negative impact is clearly not satisfactory or controlled, either due to pollution or waste. To reduce environmental footprint to the minimums, will require a new way to look to industrial sectors, basing goals on reducing emissions, material types and re-use, on all the stages from the production process. The strong message to induct this change of industrial philosophy must come from corporate, governments and consumers;

• **Renewable Resource Systems**: The global use of natural resources, either from oceans, forests, or water systems are over pressured. A high society demand is expected for the upcoming times, transversal to all activities. Governments and global institutions and authorities must focus on reforms. To conserve and manage resources wisely, it will require multilateral agreements and funding. The targets must pass from simply satisfying population needs, but to conserve and keep sustainability of resources.

All these sectors require challenging but mandatory choices to deal with and manage the limited resources. This route will have a political and economic impact. It turns evident that social concerns on sustainability are not just a philosophic approach but a requirement to hit economic and ecological sustainable goals. It is a fact that local and national authorities are more sensitive to sustainability exigencies, but is also relevant that corporations, governments and international organizations may define and coordinate a global strategy. It is though relevant that a democratic system, citizens participation and basic needs satisfaction, are mandatory for a new and sustainable development (Munn, 1992).

2.1.6 Sustainability goals & tools

As a part of a new sustainable agenda, world leaders in September 2015 at a historical UN summit, settled the 17 Sustainable Development Goals (SDGs) for the 2030 Agenda for Sustainable Development. In the first day of 2016, these goals have come into action, to be achieved in the next fifteen years (Bressmann, 2004). The new 17 Goals will be applied to all countries, mobilizing resources to finish all kinds of poverty, inequalities and fight negative climate change. It was also re-assured the idea of no one should be left behind on this route. The indicated Sustainable Development Goals (SDGs) is a way forward after the success of MDGs (Millennium Development Goals), assuring more ambitious goals to eliminate all types of poverty. These new goals set are universally calling all countries for action, independently of their richness position or social development and prosperity. One of the most relevant goals is the protection of the planet. It is thought globally recognized that finishing the poverty must be in line with a strategy that allows to build-up a solid economic growth, allowing and assuring in the same time, social basic needs such as health, education, social equity and opportunities. Fight the climate change and protect the environment is part of the puzzle (Bressmann, 2004; Pradhan *et al.*, 2017). The Figure 3, illustrates the 17 goals, accordingly to the UN representation.

Figure 3 - 17 Sustainable Development Goals (SDGs) (Bressmann, 2004)

Despite the fact SDGs are not legally imposed on countries, is commonly assumed that each of the partners must assure the establishment of internal frameworks, tools and governance criteria, to reach the accomplishment of the goals. The 17 Sustainable Development Goals (SDGs) were broke down in 169 targets within the new agenda. To measure these targets follow-up and accomplishments, a set of global indicators were introduced by the Inter-Agency and Expert Group on SDG Indicators (IAEA-SDGs), in March 2016 (Bressmann, 2004).

The presented goals represent the three aspects of sustainability, and can be divided into the following way (Weinberger, 2015):

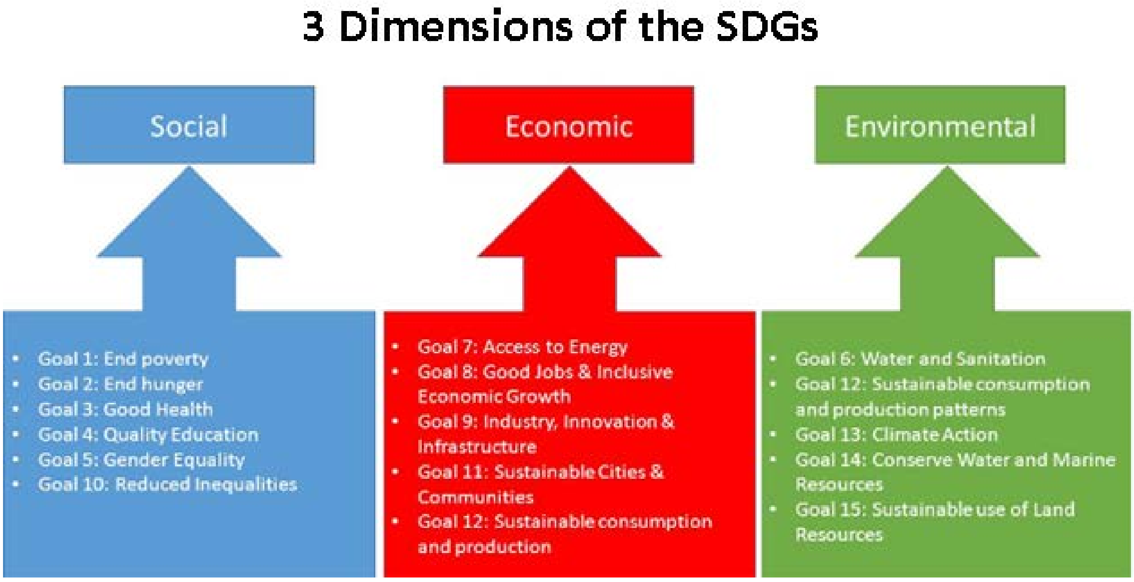

Figure 4 – Three dimensions of Sustainable Development Goals (SDGs) (Ogbonna, 2018)

Accordingly, to the United Nations definition (Bressmann, 2004)"*Goal 12: Ensure sustainable consumption and production patterns (…) Sustainable consumption and production aim at "doing more and better with less," increasing net welfare gains from economic activities by reducing resource use, degradation and pollution along the whole lifecycle, while increasing quality of life. It involves different stakeholders, including business, consumers, policy makers, researchers, scientists, retailers, media, and development cooperation agencies, among others. It also requires a systemic approach and cooperation among actors operating in the supply chain, from producer to final consumer. It involves engaging consumers through awareness-raising and education on sustainable consumption and lifestyles, providing consumers with adequate information through standards and labels and engaging in sustainable public procurement, among others*." (United Nations, 2018).

The Goal 12 focused in ensuring sustainable consumption and production patterns, is particularly relevant for this study, considering the 12 official targets described (Bressmann, 2004):

- Implement the 10-year framework of programmes on sustainable consumption and production, all countries acting, with developed countries taking the lead, considering the development and capabilities of developing countries;
- By 2030, achieve the sustainable management and efficient use of natural resources;
- By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses;
- By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their lifecycle, in accordance with agreed international frameworks, and

significantly reduce their release to air, water and soil to minimize their adverse impacts on human health and the environment;

- By 2030, substantially reduce waste generation through prevention, reduction, recycling and re-use;
- Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle;
- Promote public procurement practices that are sustainable, in accordance with national policies and priorities;
- By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature;
- Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production;
- Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products;
- Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, in accordance with national circumstances, including by restructuring taxation and phasing out those harmful subsidies, where they exist, to reflect their environmental impacts, taking fully into account the specific needs and conditions of developing countries and minimizing the possible adverse impacts on their development in a manner that protects the poor and the affected communities.

Within these targets, is given a special emphasis to key factors such as "sustainable management and efficient use of natural resources", "substantially reduce waste generation through prevention, reduction, recycling and re-use", "Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle", "procurement practices that are sustainable, in accordance with national policies and priorities", "people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature", "Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production" (United Nations Developing Program (UNEPD), 2018). There is a clear message for companies to focus on efficiency, not only from the industrial processes' perspective, but through all the supply chain; from the sustainable and selection of materials, to energetic efficiency, re-use and waste reduction. The former commissioner (2014-2019) Karmenu Vella for UN Environment, Maritime Affairs and Fisheries refers right after the new goals establishment in 2016: "The coming months will see many more initiatives in areas such as green public procurement, eco-design, food waste, plastics, water re-use, chemicals and innovation. These represent many small steps that will, I hope, bring us much closer to the new economy we need." (Vella, 2016).

Some practical tools were discussed to get started with the SDGs. These tools are aligned and cascading from four basic implementing steps (Sustainable Development Solutions Network, 2016):

i. Initiate an inclusive and participatory process: Raising awareness of the SDGs and engaging stakeholder collaboration to achieve the goals and targets;

ii. Set the local SDG agenda: Translating the global SDGs into an ambitious yet realistic agenda that is tailored to the local development context;
iii. Planning for SDG implementation: Deploying goal-based planning principles and mechanisms for more sustainable social, economic and environmental outcomes;
iv. Monitoring and evaluation: Ensuring that SDG implementation remains on track and developing local capacity for more responsive and accountable governance.

These four steps will be guiding countries and local authorities (cities and other stakeholders) to organize and guide the SDG process, by providing tools for kick-starting. Anyway, the recommended tools are not fixed neither are mandatory, but a guide that must be adapted accordingly to each reality (Sustainable Development Solutions Network, 2016).

2.2 Eco-Design

The Eco-design concept emerged in the nineties, based on the search of industries for best practices, to reduce their processes' negative impact on the environment. There are many different names to describe the introduction of environmental aspects, into product concept: DfE – "Design for the Environment", "environmental design", or "green design". The "eco" prefix though, allows to identify the term "eco", of "eco-design", not only with the ecological requirements, but to consider social and economic aspects as well. The "design" part refers to the project, plan and creative part to solve a need. The eco-design needs flexibility and open area to absorb different approaches and methods (Vicente *et al.*, 2011; Marques *et al.*, 2017).

The products' lifecycle has an impact on the environment from the early stage on raw materials consumption, to the manufacturing processes, packaging, logistic, transport, use, disposable and recycling. The design phase is responsible for 80% of the product's environmental impact. It means that, design stage must anticipate and have in consideration all potential consequences from the product (European Commission, 2012). Figure 5 is one of the many ways to represent the lifecycle framework, where Eco-design is part of the early stages to assure a final product compliant with the environmental requirements.

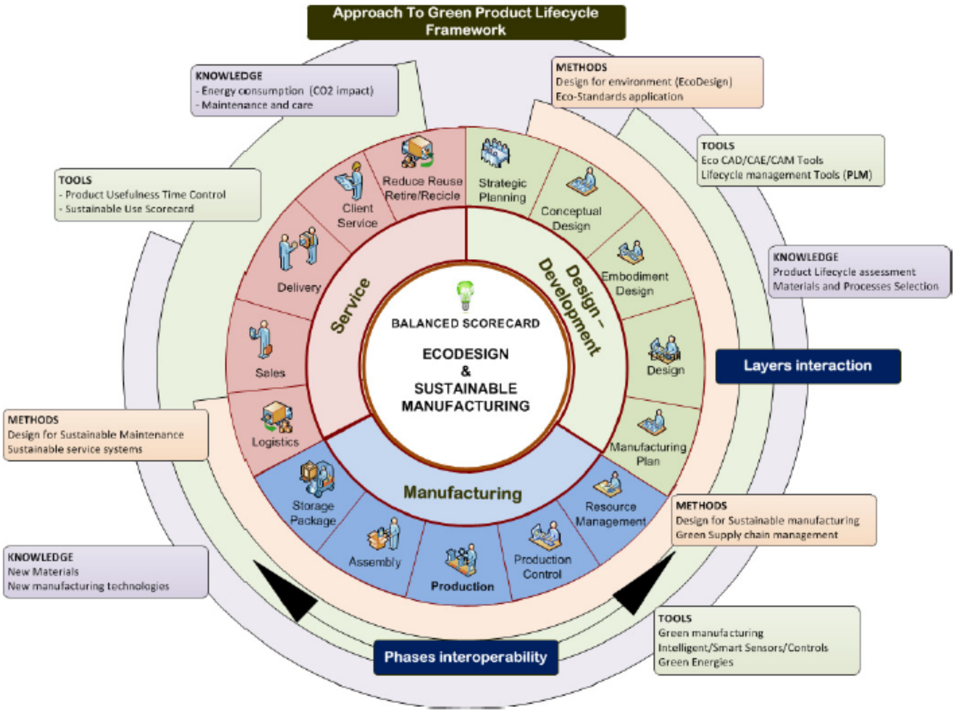

Figure 5 - Initial approach to product lifecycle(Vila *et al.*, 2015)

The design process comes from different sources such as engineering, architecture or industrial design, by putting in place the challenges to be considered to reduce the negative impact on environment. At the same time, it creates eco-friendly products and concepts, respecting environment with the same relevance as product and industrial process efficiency, aesthetics, cost, ergonomics and functionality. The Eco-design process requires a coordinated product planning providing a consistent and integrated framework, allowing to set the requirements for the products (Agudelo *et al.*, 2017; Marques, 2017). For eco-design, the main goal is always to seek for preventing instead of re-use, and the re-use preferred over recovery, etc. (Wallhagen, 2016).

In 2013, the case of domestic electric and electronic devices, as washing machines for example, were required to generate an energy consumption below the 0.5 W when in off mode. It is not a requirement of the Eco-design though, to reduce the product functionality, safety, health and access from customer to the product. The European Commission as a methodology to define eco-design assessment and requirements for a certain product (Biois, 2013; Bundgaard *et al.*, 2015; Dalhammar, 2016).

In a systematic approach, Eco-design can be defined as an integrated process where product design and conception intend to minimize environmental impact along its lifecycle, from material selection to product's end-life (Rousseaux *et al.*, 2017). Eco-design needs to be managed in an integrated part of the management and operations of the manufacturing company, since it widely connected to all areas of the company (Boks, 2006; de Aguiar *et al.*, 2017). This approach needs to be supported by the top-management by assuring the following task as suggested by the ISO4006 (The International Standards Organisation, 2011):

a) The first task concerns the strategic aspects of Eco-design, in particular with reference to:

I. *strategic product planning and integration of Eco-design into all operations of the organization,*
II. *allocating resources (human, technical and financial) for the planning, implementation and improvement of Eco-design,*
III. *changes in external market conditions and opportunities arising from technological developments, improvements in the product system and supply chain management,*
IV. *setting objectives for environmental performance,*
V. *promoting innovation and development of new business models, and*
VI. *contributing to value creation.*

Previous management reviews can contribute substantially towards this task.

b) The second task is the management of the internal processes once the Eco-design strategy and the Eco-design focus has been set. This includes:

I. *integration and implementation of the chosen Eco-design strategy in all relevant procedures, programmes and roadmaps,*
II. *ensuring a cross-functional approach,*
III. *involving the total value chain in the chosen design strategy, both upstream (suppliers) and downstream (after sales, service providers, recyclers), and*
IV. *fostering two-way communication, both in the internal and external value chain.*

To make sure that these processes develop in an optimum way, the setting up of a process performance measurement system can be of great help.

This International Standard ISO 14006 consolidates for the first time, the three areas of knowledge about the integration of eco-design within an Environmental Management System as represented in Figure 6 (Brones *et al.*, 2017).

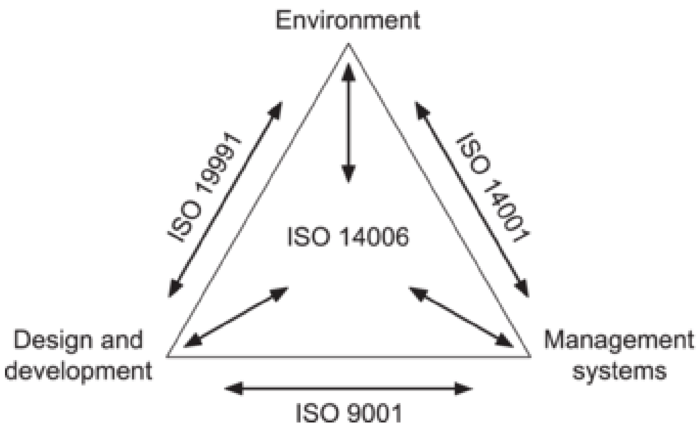

Figure 6 - Relationship between ISO 14001, ISO 9001, ISO 19991 and ISO 14006 (The International Standards Organisation, 2011)

2.2.1 Main Principles

The Design for Environment (DfE), or Eco-design, is a trendy focus for industrial designers and manufacturers. There is a guideline, driven by sustainable development philosophy, to gather an environmental concern, an economic viability and social wellbeing. Designers are now dedicating their attention to material selection, resources, manufacturing processes and recycle or re-use (Fijał, 2007). The DfE can result from the material selection, design accordingly to logistic requirements, design for an efficient and cleaner production and design for a sustainable consumption. Here are some of the Eco-design main principles (Grant *et al.*, 2015),(de Aguiar, 2017):

Selection of materials:

- by using non-hazardous materials;
- by using environmentally friendlier materials;
- by using alternative materials to those that harm the environment and society.

Design for sustainable (reverse) logistics:

- design components such that can be easily identified and disassembled for recycling, and reduce time for disassembly (Design for deconstruction);
- minimize space and weight to reduce the need for fuel and freight costs;
- by reducing the need for materials;
- by reducing the need for packaging;
- design closed-loop reverse logistics process into the products.

Design for cleaner production:

- use materials and production techniques that allow a less energy and water consumption;
- use cleaner technology to avoid using a hazardous substance in production;
- design cleaner production techniques for new products.

Design for sustainable consumption:

- produce durable products to avoid wastage;
- design products that require less energy and water during use.

2.2.2 Eco-design within a comprehensive Environmental Management analysis

Within an organization, especially in industrial cases, the decision process to support a Sustainable Product Development policy, require an analysis of a much broader pack of information than just focusing on the product (WRAP, 2013). To collect all the relevant information, from the internal processes, regulation to suppliers placed worldwide is quite challenging. To support this process, several methods and tools were developed to gather and cross data, for analysis (Choi *et al.*, 2003). These tools can be classified based on four main categories, such as: “Sustainable Development Concepts”, “Environmentally Conscious Manufacturing tools”, “Environmentally Conscious Management tools” and Environmentally Conscious Economic tools”. In each of these categories, one can find several resources to support and sustain management decision (Choi, 2003). The eco-design, an Environmental Conscious Management tool, requires environmental impact related data, on a design and management stage (Paula Pinheiro *et al.*, 2018).

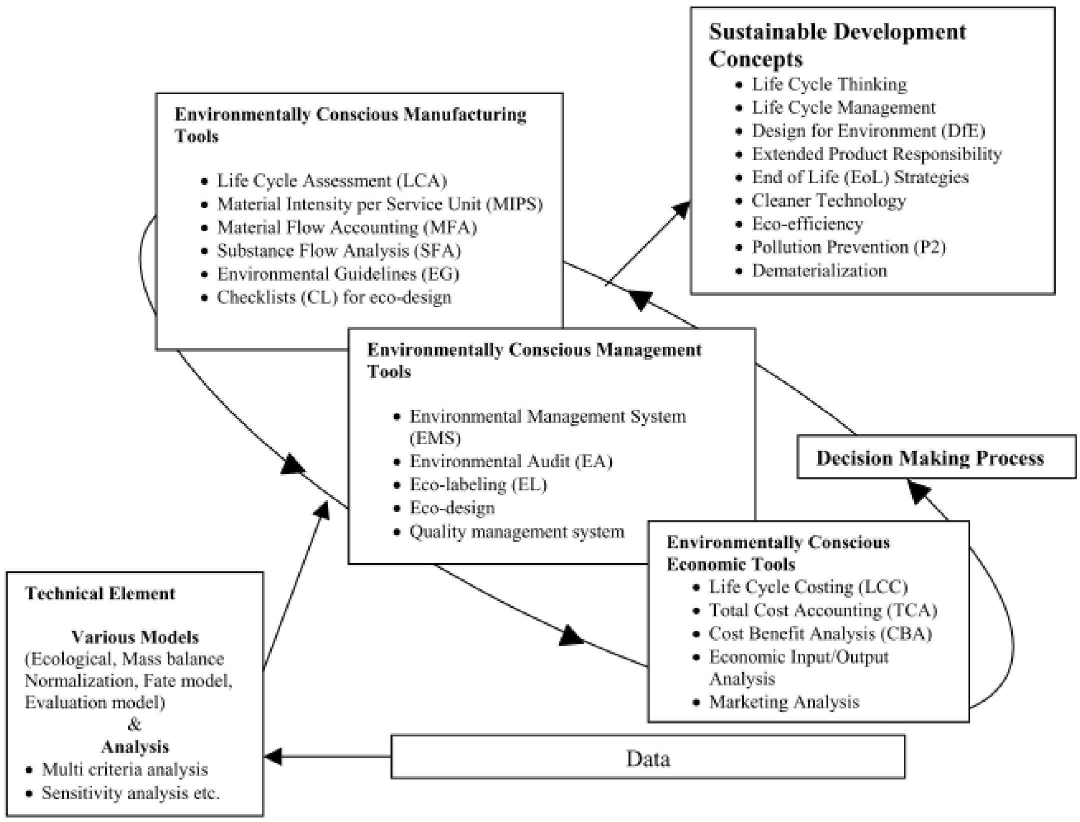

Figure 7 - Overview of generic tools concerning environmental management (Choi, 2003)

The eco-design target is to avoid significant impact on the environment during the lifecycle of the product, from the raw materials selection and to product design, manufacturing processes, distribution and disposal. Considering that the most part and relevant data arrives from company's supply chain instead of company's manufacturing plant, operations, or customers, then Supply Chain Management (SCM) must be the relevant part of the process when is considered to implement eco-design practices (Choi, 2003; Vieira *et al.*, 2016).

The process for Eco-design should be implemented during the early stage of the product development leading to improved specifications under certain criteria. Many small-medium size companies are moving towards the eco-design implementation on their reality. Anyway, is also true that there are some difficulties to obtain data from suppliers or to get support and clarification about the process. Therefore, the process is still in a very early-phase of implementation by industrial companies or other organizations. Additionally, there are not so many scientific studies about the eco-design process in line to the ISO 14006:2011 (The International Standards Organisation, 2011; Navajas *et al.*, 2017).

This process can be categorized into six steps accordingly to ISO 14006:2011: (i) Specify product functions; (ii) Environmental assessment of products; (iii) Strategies of improvement, where a strategy of product improvement is selected according to results of step (ii); (iv) Develop environmental objectives based on the improvement strategies; (v) Establish a product specification addressing the environmental objectives; and finally (vi) Develop technical solutions to meet the environmental objectives (Van Holsteijn en Kemna (VHK), 2015; Navajas, 2017).

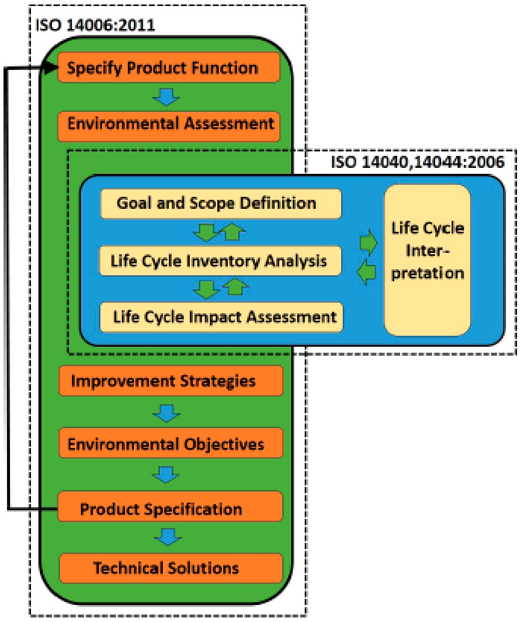

Figure 8 – Eco-design Methodology Flowchart (The International Standards Organisation, 2011; Navajas, 2017)

After specifying the product function - step (i) -, the step (ii) of the process, the Environmental assessment of products, is probably the more controversial thus difficult to achieve. Within the step (ii), the main goal is to identify what stage, or lifecycle part, can have the biggest impact on the environment. The standard for eco-design though, does not indicate what tool should be used to identify this impact. Until now, the eco-design technicians have been using some qualitative or semi-quantitative methodologies such as MET (Materials, Energy, and Toxicity) matrix. This tool can be questionable, and it has in fact caused some distrust regarding the eco-design adequacy, becoming one of the reasons why its implementation has been lagging. To create a reliable methodology, it should include not only a qualitative but a quantitative method as well, to make it an objective tool to perform the environmental impact analysis (Navajas, 2017).

The following chart below, enhances the main requirements and guidelines for the use of ISO 14001 and the specificities of ISO 14006, in the implementation of an EMS contemplating eco-design (The International Standards Organisation, 2004, 2011).

General requirements

The organization must establish, to document implement, keep and permanently improve an Environmental Management System accordingly to ISO 14001 specifications, and to define how to achieve them.	When implementing the Environmental Management System, the organization should look at the development and design process and to the environmental aspect of the products. Therefore, is mandatory to include the product development and design into the target of the EMS since it has a great impact on the final environmental impact.

Environmental policy

The top management needs to put in place the organization environmental policy and assure that, within the defined framework for its environmental management system: · it has an appropriate to the scale, nature, and environmental impacts of its activities, products and services; · it has a commitment to continuous improvement and pollution prevention; · it commits to comply with the specific requirements and others that the organization endorses regarding its environmental aspects; · it defines a framework, establishing and updating environmental objectives and targets; · is documented, implemented and maintained; · it is communicated to everyone working for, or on behalf, of the organization; · it is available to the public.	To allow top management to define its commitment to eco-design, it is vital that the policy: · Be in line with the significant nature, scale and environmental impacts of the products throughout their lifecycle; · include a commitment with: - compliance with applicable legal and other requirements that the organization endorses regarding the environmental aspects of its products; - continuous improvement of the eco-design process; - continuous improvement of the environmental performance of the organization's products throughout the lifecycle, by not transferring the adverse environmental impacts from one stage of the lifecycle to another, or from one category to another, unless this results in a net impact reduction adverse to environmental impacts throughout the lifecycle. · Provide the framework for establishing and reviewing the product-related environmental objectives and targets.

Planning

Environmental aspects

The organization needs to establish and implement one or more procedures to: · Identify the environmental aspects of your activities, products and services; · Determine the aspects that have or may have a significant impact(s) on the environment. The organization should document this information and keep it current. The organization shall ensure that significant environmental aspects are considered in the establishment, implementation and maintenance of its environmental management system.	The process of identifying and assessing environmental aspects should explicitly include the lifecycle of the organization's products to be designed, or those to be redesigned. The objective is to determine which aspects have or could have a significant impact on the environment. This generally follows the stages defined below. Identification of the environmental aspects related to the lifecycle of products that can be controlled or influenced by the organization (consumption of materials, energy, water, waste, emissions and

	others). Assessment of environmental aspects to determine their significance. During the design process, the organization shall consider all relevant environmental aspects, ensuring that significant ones are considered in establishing its environmental objectives.
Legal aspects and other requirements	
The organization needs to establish, to document, implement, maintain and continuously improve, an environmental management system in accordance with the requirements of this Standard and determine how it will meet those requirements. The organization must define and document the set of its environmental management system.	The organization should pay attention to its the design and development process, as well as to the environmental impacts of their products. It is essential to include the design and within the scope of the EMS, since it has an influence on the environmental impact of products.
Objectives, goals and program(s)	
The organization needs to establish, implement, keep the environmental objectives and targets documented, at all levels and functions within the organization. Objectives and targets should be measurable and consistent with environmental policy, including commitments concerning pollution prevention, compliance with legal requirements and others based on continuous improvement.	Defining relevant objectives is mandatory for the success of an eco-design process. The objectives related to the environmental aspects' products may be: · Horizontal (applicable to all types of products of an organization); · Product specifics; · Related to the eco-design process.

Figure 9 – Main requirements from ISO14001 and ISO 14006 (Vieira *et al.*, 2013)

2.2.3 Eco-design Tools

The Eco-design tools can be divided into Quantitative and Qualitative. The qualitative approach is simpler to implement, allowing to identify positive returns from trade-off cases when the environmental issue is simple enough. These tools can also be implemented in the early stage of product development because they do not require the introduction of a relevant amount of data. However, they are not credible enough to develop decision-support algorithms. In the case of quantitative tools, they are more useful when it is necessary to introduce a detailed environmental profile to support decision making. It is found, however, that these tools have more difficulty to be implemented at an early stage of the process, since they require a lot of information often not available until the end of the process. In this final phase, it is more difficult to implement significant modifications, allowing only minor changes.

Some main tools will be developed in this chapter, but there is an extensive list of different tools created along the years, as it can be seen in the ANNEX I (den Hollander *et al.*, 2017)(Andriankaja *et al.*, 2015).

2.2.3.1 Quantitative Design Tools

The Life Cycle Assessment (LCA), is a common and accepted tool to determine the environmental characteristics of a product. The LCA has been frequently used to minimize materials, energy and environmental waste during the product design and manufacturing process (Zampori *et al.*, 2016). The LCA is used since the seventies by scientists, since then, many standardization bodies have been trying to systematize and improve this assessment process. As result, the ISO 14040:2006 and 14044:2006 norms have established a framework to guide an accurate LCA analysis. The eco-design standard described with the ISO 14006:2011 can be applied to industrial products (The International Standards Organisation (ISO 14044), 2006; Knight *et al.*, 2009).

2.2.3.2 Qualitative Design Tools

To counteract the limitations mentioned above and to adapt tools to the needs of each context, simpler and qualitative versions have been developed (Rossi *et al.*, 2016). Although they allow the incorporation of several environmental criteria, the more summarized, the less reliable they become. In this large group, it is possible to identify four typologies of tools to be analysed:

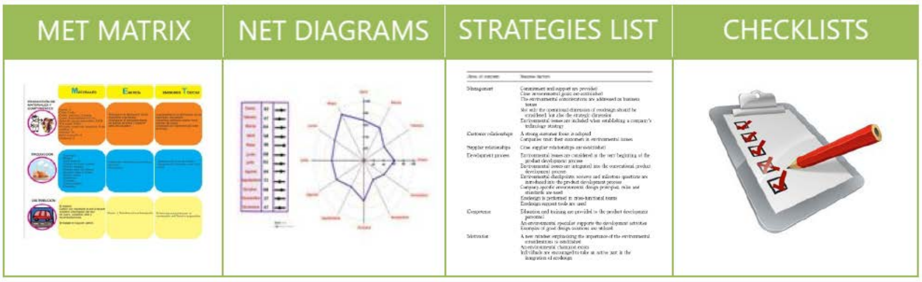

Figure 10 – Main qualitative design tools (Vieira, 2013)

Among the matrices, it is possible to find one of the most used eco-design tools: the MET Matrix. This is a table that runs through the product lifecycle according to three MET columns - MATERIALS, ENERGY and TOXICITY. It is possible to describe the resources used, by and in the product, at different stages of its lifecycle. This synthesis can be done based on quantitative information originating from a lifecycle assessment or a more qualitative assessment. Most of the existing matrixes also serve to assess impacts, whether existing products, developing solutions, and/or prioritization, although they do so in different ways and setting priorities (Vieira, 2013).

Network diagrams (also known as polar diagrams) are the second typology of tools widely used in eco-design. They are simple and time-saving tools. However, if they are supported by a more extensive analysis of the product lifecycle, they may require more time to complete but returns with much more accurate results. Graphically, they are all very similar: they appear as a spider web, in which in the several axes (usually between 5 and 8) certain criteria or aspects are evaluated. The union of the qualitative classification that is given in each axis allows creating an area that visually translates the impact of the product. The criteria or strategies placed on each axis are the main variations between the different versions of the tool. Versions may exist with an analysis of specific strategies of a company, with sector-specific strategies, or by following the lifecycle in a generic way (Midžić *et al.*, 2015; Jayatilaka *et al.*, 2016).

The third type, lists of strategies, encompasses several tools with lists of eco-design strategies or gold rules to use in the product development process. They are generic tools, which means they are more extensive and less focused, or allowing customization. They are very simple tools requiring little time to apply, but if they are oriented to a specific company or sector, they may be very useful (Midžić, 2015).

The fourth typology refers to the checklists which are usually longer and more exhaustive lists than the lists of strategies and allow a small evaluation of each listed criterion. They are tabular lists, which detail various criteria in each category, whether they are design strategies or the lifecycle phases (Masoudi *et al.*, 2012).

The following figure presents some examples of tools of this typology, as well as of the other typologies identified (Andriankaja, 2015).

MET MATRIX	NET DIAGRAMS	STRATEGIES LIST	CHECKLISTS
• *Dominance Matrix*	• *Eco-Compass*	• *10 Guidelines for Ecodesign*	• *Ecodesign Checklist*
• *Ecodesign Priority Matrix*	• *Ecodesign Web*	• *Econcept Strategy List*	• *Phillips Fast Five*
• *Ecodesign Project Planning Matrix*	• *LiDS Wheel/Ecodesign Strategy Wheel;*	• *Expert Rules*	• *Volvo's Black List*
• *Eco-portfolio Matrix*	• *Smart ecoDesign Electronics Strategy Wheel*	• *Rules of Thumb*	
• *Product Summary Matrix*	• *Sony Polardiagram*	• *Ten Golden Rules*	
	• *Spiderdiagram Econcept*		

Figure 11 – Examples of other qualitative design tools

Some tools, considered the most relevant in the process of implementing an eco-design project, will also be developed: Life Cycle Assessment (LCA), Eco-design or Life-Cycle Strategies Diagram (LiDS Wheel) and Eco-design Checklists (Vicente, 2011),(Magerholm, 2014).

2.2.4 Main tools Application

2.2.4.1 Life Cycle Assessment

The Life Cycle Assessment (LCA) is the most commonly used tools to evaluate the product lifecycle, during its entire process, and based on criteria analysis. This tool is described by the ISO 14040:2006 Environmental management - Life cycle assessment -- Principles and framework as the "*compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its lifecycle*" (International Standard Organization, 2006).

There are two main understandings of the product lifecycle, one more focused on marketing and strategy, dividing the analysis into five phases: *introduction, expansion, maturity,* *saturation and decline* of the product. The other perspective is connected to the function side of the product, and more broadly adopted by all designers working in the design process. Is possible to identify three categories of analyses connected to this second definition of lifecycle focused on the functionality: the company level, the team level and level defined by experts. On an organization level, the lifecycle is the global process of: design, manufacturing (including procurement and assembly), distribution, maintenance, collection/disassemble, re-use, disposal, recycling (Wiche *et al.*, 2014). Anyway, experts have a different perspective: the holistic view considers the environmental impacts as well along the product's lifecycle, since the extraction of raw material to the final elimination(de Aguiar, 2017). The ISO/TR 14062 defines life-cycle as "*the successive and linked phases of a product system from the acquisition of the raw material to their final elimination*" (de Aguiar, 2017).

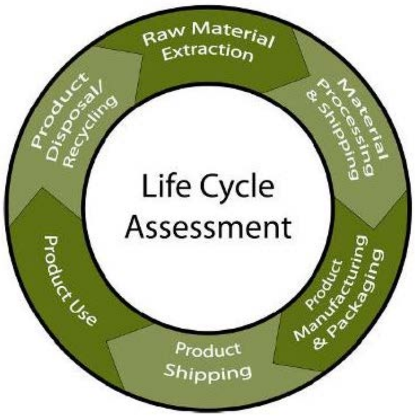

Figure 12 – Life Cycle Assessment illustration (Kikuchi, 2016)

As indicated before, the lifecycle concept can vary at different levels and design is all about a mix of processes where different pieces of knowledges and competencies are involved. The responsibility for the design must put together transverse limitations as the environmental aspects, a job that can become the process quite complex (Rio *et al.*, 2011; Bonou *et al.*, 2016).

The methodology is based on the principles set out in the following topics (Agudelo, 2017), (Lee *et al.*, 2004), (International Standard Organization, 2006; Khasreen *et al.*, 2009):

DEFINITION OF THE PURPOSE AND SCOPE
The main goal should describe the application of the study, the reasons for its realization and the intended target audience. In the case of application to product design, the purpose of the study should be connected to the same goals of the product development target. When the product development team uses this methodology, it aims to know: • What are the main environmental problems of a product? • What is the most environmentally sound design alternative? The scope of the study must define: • Product system to be studied: the system consists of the set of operations that constitute the life of the product and which will be considered for the study. The definition of the systems to be studied depends to a large extent the objectives established for the study of stroke; • The function of the product system, i.e. what is the function to be performed by the product

being studied and what consumer's needs will the product respond to;

- The functional unit to be used in the study, which consists of a measure of the functional performance of the system, is the performance of the function performed by the product. The functional unit will serve as a reference for which input, and output data are to be determined in the lifecycle inventory. In the case of comparative studies between systems which have equivalent functions, the functional unit shall allow comparison of the different systems in the study;
- System boundaries (spatial and temporal): separate the system from its surroundings and through them that the inputs and outputs of materials and energy from and to the system under study occur;
- Selected impact categories and impact assessment methodology, such as aggregation factors of global problems (such as the greenhouse effect) with local problems (such as pollution of a sensitive natural area) and the subsequent interpretation to be used;
- Information requirements;
- Initial information quality requirements, including variability and uncertainty;
- Supported assumptions;
- Limitations (technical, temporal, knowledge, financial, human resources, among others possible);
- Type of critical review of the study, if deemed necessary (internal review by a specialist or interested parties);
- Type and report format to display, depending on the selected audience.

LIFE CYCLE INVENTORY

This phase is the central part of the LCA, involving most of the time spent in the study. The lifecycle inventory consists of a process of data acquisition: quantification of materials, energy consumption, liquid and gaseous emissions, solid wastes and others throughout the entire lifecycle of the product. These data are organized into databases and process flowcharts forming the basis for the next phase: the assessment of life-cycle impacts. With the process tree and the quantification of the inputs and outputs made, it is now possible to do the inputs and outputs inventory, of the materials and energy associated with the product. The result is the inventory resume.

IMPACT ASSESSMENT

In this phase, the information is processed, with the selection of the information oriented to the evaluation phase of the impacts. Impact assessment can lead to an iterative review of objectives and scope, whether due to insufficient information, either because it is more useful focusing attention only at a more problematic stage of the life and not the entire system, which can save time and resources. The general impact assessment methodology includes mandatory elements, namely:

- Selection of the impacting categories, the category indicators and characterization models;
- Imputation of inventory results (classification);
- Calculation of category result indicators' (characterization) and optional elements (calculation of the magnitude of the category indicators' results related to the reference information (normalization);
- Aggregation;
- Weighting.

RESULTS INTERPRETATION

At this stage, the results of the inventory and the impact assessment are interpreted in accordance with the objectives defined to reach conclusions, explain the limitations and the decision-makers. The interpretation phase may also involve reviewing the scope of the LCA study, as well as the nature and quality of the data collected, in line with the objectives established for LCA.

As part of the product development process, LCA allows the detection of environmental impacts associated with a design alternative, as well as what stage of their lifecycle impacts, allowing in this way to guide the design process to solve these problems.

2.2.4.2 Life Cycle Design Strategy Wheel

The Life Cycle Design Strategy Wheel (LiDS Wheel) also known as Eco-design Strategy Wheel consists of a graphical representation of possible strategies for eco-design implementation within a company. LiDS Wheel is a tool of selection and communication of eco-design strategies. In the LiDS Wheel, which is presented in polar or "spider web" diagram, are present eight strategies of eco-design, namely (Vieira, 2013):

- Development of new concepts;
- Choice of materials with low associated impact;
- Reduced use of materials;
- Optimization of production techniques;
- Optimization of the distribution system;
- Reduce impact in the use phase;
- Optimization of the initial lifetime;
- Optimization of the end-of-life system.

The described strategies assume some criteria as an evaluation mode. These criteria’s scope is to answer specific questions about the old and new product, or about the traditional and innovation targets to achieve. The final classification will define the path to follow or the evolution of an old product to the new one (Buchert *et al.*, 2017).

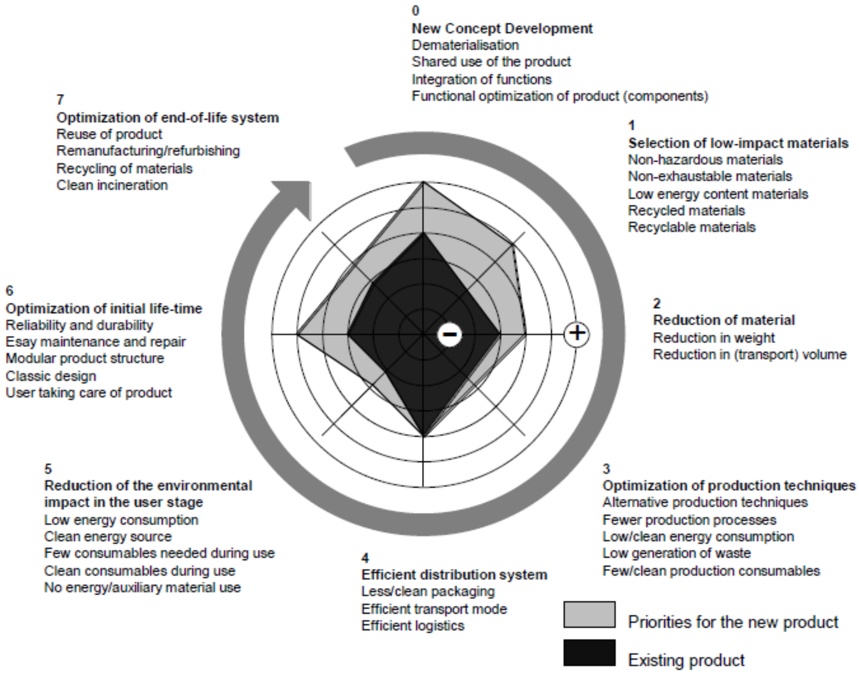

Figure 13 - LiDS Wheel adapted from (Bras, 1997; Wever *et al.*, 2017)

The LiDS Wheel is an Eco-Design tool, making part of nearly all Eco-Design methods, and which is commonly used by consultants (Wever *et al.*, 2014). The strategy of developing new concepts referenced by the @ symbol is different from all the others, appearing at the top of the diagram, rather than prominent, since it assumes an innovative character far superior to any of the others, implying a deep change to all levels of the organization. Most of the strategies are related to the product lifecycle, to all levels of product development:

- At the level of the product system (creation of a product concept);
- At the product structure level (definition of its functional structure);
- At the product component level (selection of product design details).

The LiDS wheel is thus a tool, used at any point in the development of the product, proving to be a simple and practical tool for listing the environmental aspects' impact of a product and possible improvements in its environmental performance. In addition, the LiDS wheel can also be used in a reverse way, assuming the role of an incentive tool for the generation of ideas towards improvement (Martin Charter, Scott Keiller, 2018).

For a better application, the good practices suggest using the Eco-design Strategy Diagram together with the MET Matrix and the Checklists. Is also important not to consider only technical solutions, but consider as well psychological aspects how the design influences the user in terms of energy efficiency, duration of the lifecycle, end of life, etc. (Bundgaard *et al.*, 2017). Another relevant point for a good application of the LiDS wheel tool, is to be aware that some of the eco-design strategies are complementary and they strengthen in both directions, but others may conflict. At the end of the redesign, re-analyse the product to see if it retains the physical and immaterial functionality of the old product is mandatory. Once the LiDS wheel is complete, it can be used to communicate the eco-design strategy followed by the company, for product development (Vieira, 2013).

2.2.4.3 Eco-design Checklists

The Eco-design checklists help designers to keep track of all the design aspects making sure that nothing is overlooked. The Eco-design checklists have two columns, the left one for the questions and topics to be approached and the right one with thoughts and improvement options suggested. The checklists are also related to the LiDS wheel (Masoudi, 2012).

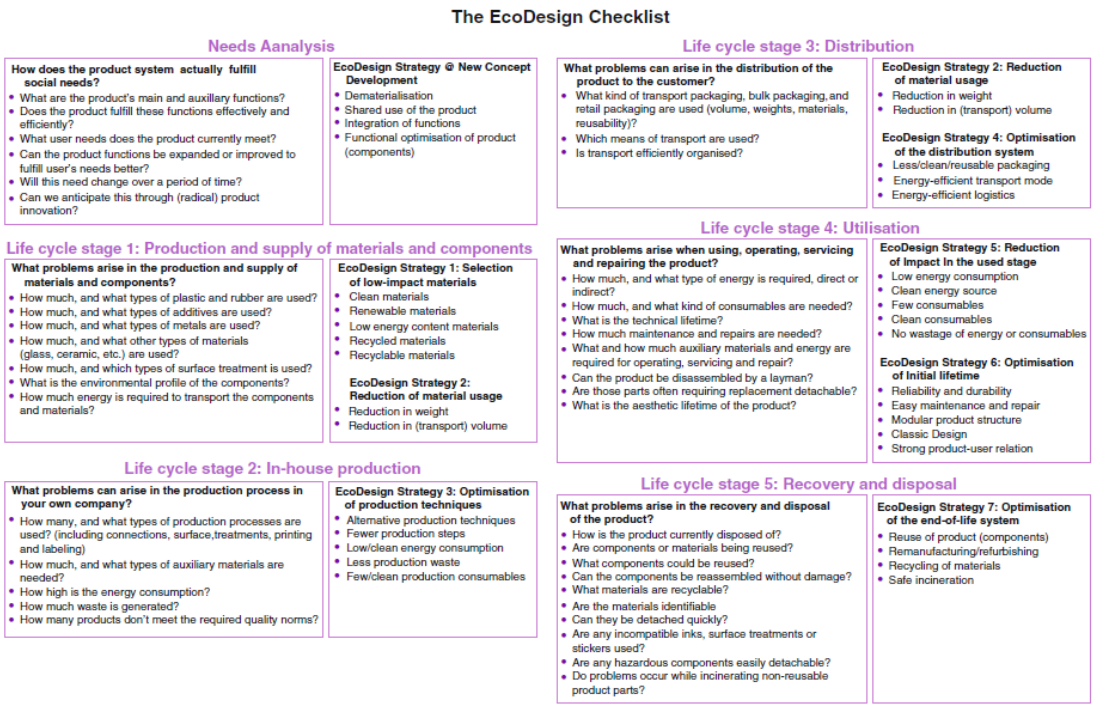

Figure 14 - Eco-design checklist (Wever, 2017)

2.2.5 Recent developments and future trends

One of the recently implemented strategies is "Dematerialization", by reducing the use and dependence of physical products. This approach would reduce material costs, distribution and energy. By dematerialization, one intends to define not only the replacement of physical products by services, but also, the size and weight reduction. Examples can be easily found from both cases such as emails replacing physical letters (and associated logistics services), as computers seeing their sizes and weights reduced drastically and most recently, the Internet of things are turning dematerialization as a fashionable trend (Vitali *et al.*, 2017).

The other recent development is to promote the Products Share instead of individual ownership. Some recent examples like car-sharing, or common laundry machines, as the equipment's being shared by several departments within companies or even co-working offices, are only a few cases where one can see real savings on unnecessary products and resources.

To provide service instead of products is the other trending strategy. In some cases, the economic rationales have shown the advantages to provide the service instead of selling equipment. A quick example can be the copy machines widely use, that was requiring a lot of maintenance and consuming parts. Most of the companies prefer nowadays to rent this equipment with maintenance compressed together with consumables. The fact this equipment is managed by dedicated companies, will become much more efficient and regularly assisted in turning the product life longer and optimized (Navajas, 2017).

A new approach is being given to all the sustainability collected data. The accuracy of the collected information from every process, is fundamental to turn corrections or improvements effective. To consolidate, uniformize and share new tools are being created to manage the massive and global data (Mieras, 2018): "*Big data is heralded as the next frontier for discovery, innovation, competition, and productivity. As sustainability experts, we can learn from that to use sustainability data to (co-)create shared value with new products and business models.*"

The other trend is the interaction of collected data with internal company's software, where LCA metrics will be taken into consideration within the whole Environmental Management System. As an example, the integration of collected data with developing software like CAD/CAE can turn the process more effective and efficient from the conception stage (Tao *et al.*, 2018).

2.2.6 Case-studies

Some companies, making use of the state-of-the-art knowledge on eco-design approach, they build-up their own tools, adapted to specific needs and industry specifics. To better understand the Eco-design analysis implemented within a renowned company, is described below an example from Siemens' study on a Base Transceiver Station (Ferrendier *et al.*, 2002):

Organisation	Siemens (Munich)
Sector	Electrical / Electronic / Electrotechnical
Product	Base station BS 240/241
Benefits, success	Environmental benefit: • 35% reduction of power uptake, • 57 000 tons CO2 saving in the first year of sales; Financial benefit: • - 50% reduction of manufacturing cost.
Tools and resources invested	**Tools:** Siemens Standards SN 36350 The six parts of the Standard are as follows: 1. Product development guidelines: • principles of environmentally compatible product design; • guidelines on environmentally compatible product design; • integration of the environmentally compatible design into the product planning and development process. The guidelines consist of forty rules for all phases. They follow a Life Cycle Approach. Focal points include: • energy consumption in the use phase, especially in the case of a long-lasting product; • reduction and recovery of end-of-life waste; • substitution of hazardous substances.

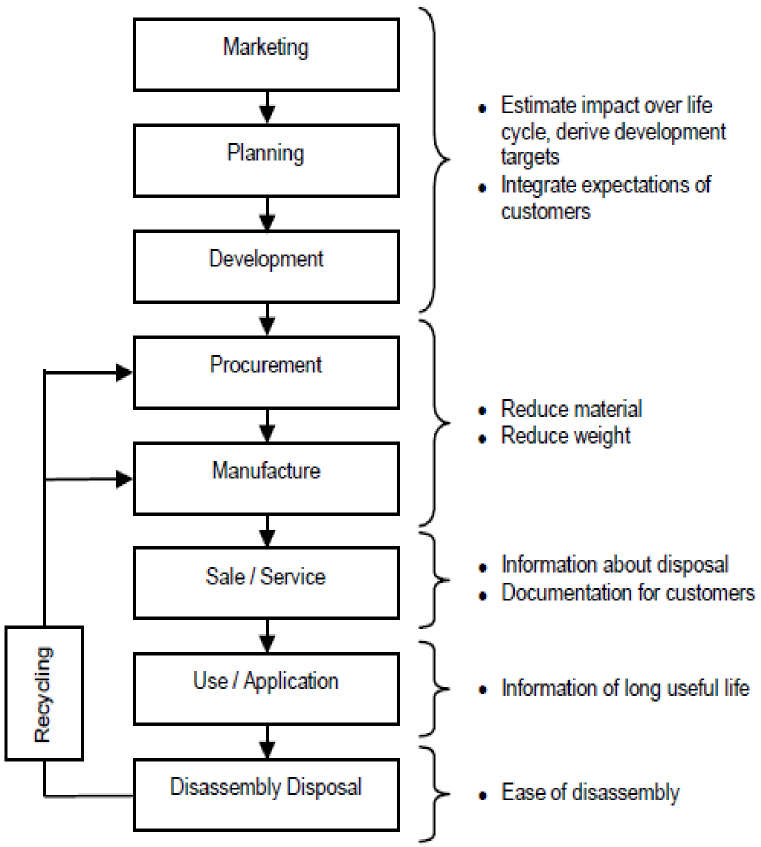

Figure 15 - Examples of input of rules into the development phase

The Base Station BS 240/241 has been developed in accordance with these guidelines. The Figure 16 – Improvement chart Figure 16 below shows the improved points, and the design process steps.

Part of the product	Guideline part	Improvement
Base station	MPD	volume reduction: 8 transmission units instead of 6,
Cooling system	MPD	volume reduction: 38%,
Base station	MPD/PM	no more outdoor air conditioning system
Cooling system	PM	weight reduction 50%
Subrack	PM	reduction of the number of material: 1 pure instead of 4
Base station	PM	manufacturing cost reduction
Subrack	PM	cost reduction: 22% instead of 100%;
Cooling system	PM	cost reduction: 33%.
Cooling system	UA	energy consumption reduction: -180W
Cooling system	UA	better heat balance: +7 K
Cooling system	UA	MTBF improvement: 31%
Subrack	DD	reduction of the number of parts (17 instead of 66),

Figure 16 – Improvement chart

Note: MPD: Marketing, Planning, Development PM: Procurement, Manufacture UA: Use, Application DD: Disassembly, Disposal

2. Hazardous substances, list of prohibited substances, list of substances to be avoided:

Informative list of legally banned or restricted hazardous substances: in

<table>
<tr><td></td><td>European Union, Switzerland and some other countries.
Siemens-specific list of substances to be avoided or declared, based on the following criteria:

- carcinogenic, mutagenic, toxic to reproduction;
- acutely or chronically toxic;
- easy formation of CMR, acutely or chronically toxic substances;
- radioactive;
- water-polluting;
- persistent and bio cumulative;
- contributing to global warming;
- ozone depleting.

If one of these substances cannot be avoided for technical reasons, it must be declared to all those who need the information, e.g. the recyclers.

3. Polymers: assessment of suitability for recycling and miscibility of thermoplastic polymers.

Gives advice on the selection of recyclable polymers not containing harmful additives. Additionally, a miscibility matrix shows which polymers can be combined without hampering recyclability. This is helpful in cases where different polymers must be joined inseparably because of technical reasons.

4. Metallic materials: classification of recycling properties and miscibility.

Classifies frequently used metals, metallic alloys and combinations of metals with respect to their recyclability.

5. Ecological requirements for packaging

- principles of environmentally compatible packaging design;
- preference list of packaging materials;
- avoidance list of packaging materials;
- prohibitions;
- marking of packaging.

6. Record of substances in products

Provisions for recording substances, which are contained in products, based on IEC Guide 113 “Materials Declaration Questionnaires – Basic guidelines”.</td></tr>
<tr><td>Problems or possible issues for improvement</td><td>Positive aspects
- The forty rules of the Siemens Standard provide wide coverage of an LCA and extend it, because LCA does not contain design principles;
- All forty rules can contribute to innovation;
- Environmental improvement (degree of fulfillment of the forty rules) can be combined with cost estimations;
- Solutions for the environmental improvement can be different.
Negative aspects</td></tr>
</table>

	- The rules might be contradictory, so the application of all of them cannot be mandatory; - The rules might not be applicable (e.g. for components); - The system to which the product is applied has to be integrated in the analysis.
Results	**Environmentally compatible design** - Base station - Volume reduction: height transmission units instead of six, - New air conditioning concept so there is no need to use an outdoor system, - Manufacturing cost reduction: Al, chem. oxidized. + coated + printed inscription replaced by noble steel + laser inscription. - Sub-rack - reduction of the number of parts (seventeen instead of sixty-six), - one pure material instead of four, - cost 22% instead of 100%. - Cooling system - weight reduction: 50%, - volume reduction: 38%, - 7 K better heat balance, - energy consumption reduction: 180W, - MTBF improvement: 31%, - cost reduction: 33%.

2.3 Pressure cylinders

The first register of under pressure vessels was mentioned in the book of Codex Madrid I, from Leonardo da Vinci in the year 1495. Basically, it describes a system where an air-pressurized cylinder plays a lift to elevate weights within the water. These containers though, that is similar to the nowadays concept, only came to the market in the nineteen-century during the Industrial Revolution, where the steam generation was done in boilers. The poor quality of materials concept, manufacturing processes, use and maintenance caused a lot of incidents, some with a fatality. Many advances were made on the pressure vessels engineering process, from the testing, analysis, materials, welding and corrosion. The safety standards also were improved with the accurate assessment of vessels' stress, by using for example, Finite Element Analysis (Nilsen, 2011).

Pressure vessels are used for the transport and storage of Liquefied or compressed gases since around 1810. Anyway, high-pressure cylinders for compressed gases only appeared in 1890, with the seamless models launched by Mannesmann Company in Germany (The Compressed Gas Association, 2013).

2.3.1 Business

The pressure cylinders have nowadays several and very diverse applications. A wide number of products can use pressure cylinders, from consumer products such as fire extinguishers, cooking, balloon gas, up to industrial use such as chemical, oil and gas, heating equipment, welding, etc.

One can identify three types of different uses for pressured cylinders:

Compressed Gases – Commonly used with Oxygen, Helium, Nitrogen, Carbon dioxide, air;

Liquefied Gases – The most known application is for Liquefied petroleum gas (LPG), but also for Liquefied Nitrous Oxide;

Dissolved Gases – One example of dissolved gas is the acetylene; the pressure cylinder manufacture and storage, are complex.

Despite the cryogenic vapours could be considered as a gas, is classified in a different way. More information can be collected from the Storage, Transport and Handling of Cryogens Guidelines (University of Wollongong, 2012).

Within the wide numbers of vessels, one can distinguish three types of gas cylinders:

- High Pressure – The high-pressure cylinders may have very different sizes. Some gases like Helium, Nitrogen, Oxygen and Hydrogen use high-pressure cylinders.
- Low Pressure – The cylinders carrying a low-pressure content can also be offered in many different sizes. The LPG is the most known example of gas offered in low-pressure tanks, as well as the refrigerant gases and helium for balloons.
- Acetylene Cylinder type – the cylinders carrying acetylene have a differentiated process and content, using a type of internal foam with a solvent – usually acetone - where it will be dissolved (University of Wollongong, 2012).

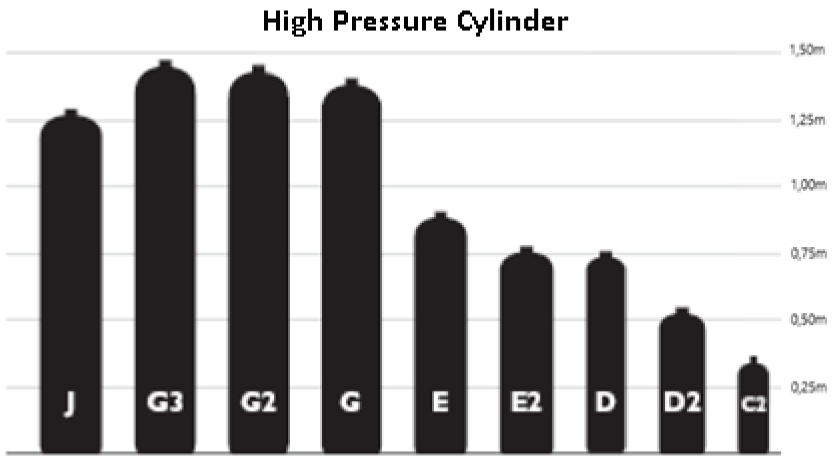

Figure 17 – Size range of high pressure gas cylinders available (University of Wollongong, 2012)

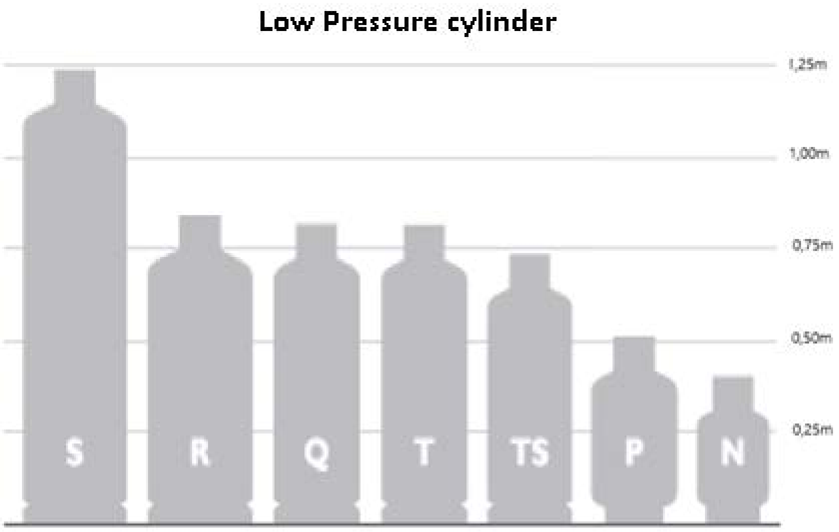

Figure 18 – Size range of low pressure gas cylinders available (University of Wollongong, 2012)

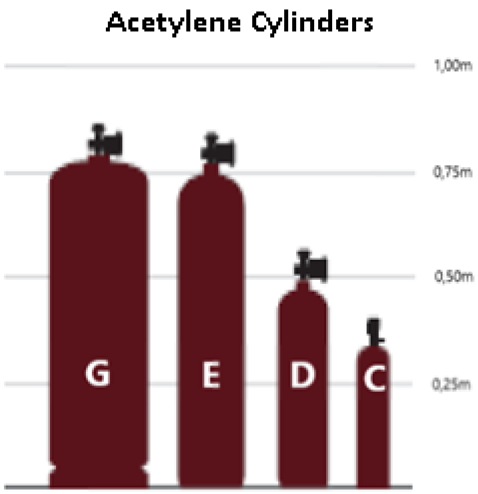

Figure 19 – Size range of Acetylene cylinders available (University of Wollongong, 2012)

2.3.2 Pressure cylinder types

The pressure cylinders can be classified into four types, based on their construction, as described below (Composites World, 2018):

Type I: All-metal construction, generally steel. Type I vessels are the least expensive, with estimated production costs of roughly $5 per liter of volume. The metalworking skills and equipment needed to produce them are widely available internationally. To their detriment, Type I vessels are the heaviest, weighing approximately 3.0 lb/L (1.4 kg/L).

Type II: Mostly steel or aluminium with a glass-fiber composite overwrap in the hoop direction. The metal vessel and composite materials share about equal structural loads. Type II vessels cost about 50 percent more to manufacture than Type I vessels, but they weigh 30 to 40 percent less.

Type III: Metal liner with full composite overwrap, generally aluminium, with a carbon fiber composite. The composite materials carry the structural loads.

Type IV: An all-composite construction featuring a polymer (typically high-density polyethylene, or HDPE) liner with carbon fiber or hybrid carbon/glass fiber composite. The composite materials carry all the structural loads.

The Type I cylinders for Compressed Natural Gas (CNG) are the most common cylinders because they are still used within transport vehicles around the world. Some researches refer that Type I will continue to be the most sold in a near future. However, the market forecast for natural gas vehicles will help to increase the Type II, III and IV pressure cylinders demand as well. This will represent a fast-growing for this technology, generating benefits from an environmental perspective, such as (Composites World, 2018):

- by using composite materials in the total, or partial, construction of cylinders, can generate savings on fuel consumption with the weight reduction. For example, if one considers a normal bus or truck, by using the Type III or IV, it can easily bring savings on the weight of the gas cylinder in more than 454 kg. This reduction allows the user to save on fuel, increase truck capacity or use it for more beneficial operating systems.
- the composite cylinders can extend the limit for gas pressures, allowing an improved storage of gas. For high-pressure cylinder, around 350 bar or more, the Type III and Type IV can represent the best options.
- The use of composite materials prevents significantly the corrosion of the tanks when compared to traditional steel-only tanks, adding the safety argument to the cylinder type. The composite cylinders using carbon fibers for reinforcement have an excellent fatigue resistance. These types of fibers can also extend the need for refurbishment. The Type III and IV (reinforced with carbon fiber) cylinder can be kept in service up to 30 years, which is the double of Type I and Type II.

2.3.3 Product requirements

There are different regulations applying to pressure vessels, depending on the region. In the United States, and commonly used in other regions internationally, the Department of Transportation (DOT) defines the guidelines to certify and approve pressure cylinders. Anyway, DOT is not accepted in Europe. The Transportable Pressure Equipment Directive (TPED) sets the requirements for the pressure vessels certification (European Parliament and Council, 2010; TÜV SÜD AG, 2014).

The TPED describes the requirements to the design of the cylinders, to the manufacturing process, the conformity assessment, as well as the period for the reassessment of transportable cylinders and other pressurized equipment. The directive not only covers the cylinder, but also the valves and related accessories. The Directive covers both refillable and non-refillable cylinders. By the other hand, the type of under pressure vessels used for storage (non-transport related) is normally under the Pressure Equipment Directive 2010/35/EU (European Parliament and Council, 2010).

A few examples of equipment covered by the Directive:

- Fuel gas cylinders
- Welding gas cylinders
- Road tankers for transport of compressed gases
- Battery vehicles containing bundles of cylinders joined by a manifold
- Containerized vessels for compressed gases
- Cylinders incorporated in life rafts and lifejackets
- Vessels for cryogenically cooled gases

The manufacturing companies not only need to assure that product performance complies with requirements, but they do need to assume its compliance by fulfilling a dedicated declaration of conformity. The registration of the technical information, describing the full manufacturing process of the cylinder is mandatory, to be supplied to the notified body.

The instructions requirements are not included, by the other hand, instructions for the use, for transport, for filling process, regular inspection, drivers' trainee etc., are included in the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR), specifically in packaging instruction P200 related to gas cylinders (United Nations, 2015).

The marks are also a relevant aspect and requirement to comply with the ADR, specifically to section 6.2.1.7 of this regulation (United Nations, 2015):

- name or mark from the manufacturer;
- number of approval (if design type cylinder is approved);
- batch or serial number from the manufacturer;
- Container tare without accessories, in cases where the inspection of thickness is made through weight verification;
- test pressure;
- year (date) of the first inspection and the month when the inspection period needs to be performed in less than ten years;
- the expert carrying the testing and inspection needs to put his stamp;
- cylinder capacity in Litres (water capacity);
- in the case of compressed gases filled at a certain pressure, it should mention the receptacle maximum filling pressure allowed, at 15 °C;
- in the case of dissolved acetylene, filling pressure allowed should be marked as well as the total of the mass of the empty cylinders, fittings and accessories, the porous mass and the solvent;
- the TPED require the Pi mark on the cylinder
- in addition, non-refillable cylinders need also to be marked with the words "DO NOT REFILL" with a minimum of 6 mm in height; also, the UN and the gas technical name are required to be marked, or in case gas mixture - between the two gases - the most predominantly contributing to the hazard's characteristic.

In the case of valves related to safety, they should be marked and comply with pi-mark or CE-mark for TPED. For other valves, is not required to have any special markings.

In general, the directive requirements are complex for understanding since many aspects are described on ADR regulation, which is a very extensive and detailed document with specific technical requirements. Anyway, when the cylinder manufacturer designs the product in accordance to the approved design specifications following the instructions of the authorized notified body for the manufacturing process, tests and for the final inspection, the cylinder is considered as compliant (Lofthouse, 2006; Conformance UK, 2018).

2.3.4 Regulations

In the previous chapters, it was mentioned the CE mark for valves and the Pi (π) mark for the cylinders. The CE mark certificates that a specific cylinder is in line with the Essential Safety Requirements (ESR) which is aligned with all the European Directives applied to the product. The CE mark is mentioned by many European directives, as mandatory for several products such as pressurized equipment, medical devices, toys, between many others. When one refers the Pi (π) marks, it reflects the compliance to the same regulation as the CE mark, but more commonly used in certain types of Transportable Pressure Equipment (TPED) (European Parliament and Council, 2010; ECE Global, 2018).

In 1985, it was approved a resolution for the regulatory and the strategy by the Council Resolution of 1985 (Resolution *et al.*, 1985) on a new approach to the harmonization and standardization of technical requirement.

The new and global approach implemented a modular approaching type, by dividing the conformity assessment, in several processes. These processes are different accordingly to the specific operation and stage of the product creation, going from the design phase to the creation of prototypes, and all production process. The required assessment to the whole process may require specific documentation, analysis, approvals and the assurance of a minimum quality. This assessment may be done by the manufacturer itself (needs approval) or by a third body. The indicated approach though, was updated and completed later by a Council Decision 90/683/EEC, and later a final version issued as Decision 93/465/EEC. The content indicated in these decisions define the guidelines for a conformity assessment (ECE Global, 2018).

The referred decision defines guidelines, among other topics, for manufacturers' internal design and production. Basically, it proves that product design itself is not just based on creativity or freehand to meet ecological targets but instead is limited by a firm limitation imposed by regulation (Matthews *et al.*, 2011).

2.3.5 Steel cylinders

The production process of cylinders can vary depending on the use, gas type, pressure size, materials, regulatory specifications etc.

Within this chapter, it will be described as basic process of a commonly used low-pressure cylinder. This kind of low-pressure cylinders has two parts/halves got from deep drawing process, welded through submerged arc welding. These two parts will build the body of the cylinder, sustaining the cylinders content and pressure. In addition, the cylinder body requires a sustainable foot, and a neck. Both neck and foot have similar construction, being cut from a steel band and submitted to a stamping/cutting process, followed by calendar machine to give the circular shape, and finally marked with series and regulatory information. Moreover, helping the transport of the cylinders, the neck part also protects the cylinder valve from an impact. The valve, depending on the cylinders, is welded to a disc that, it is itself welded to the top and centre of the body.

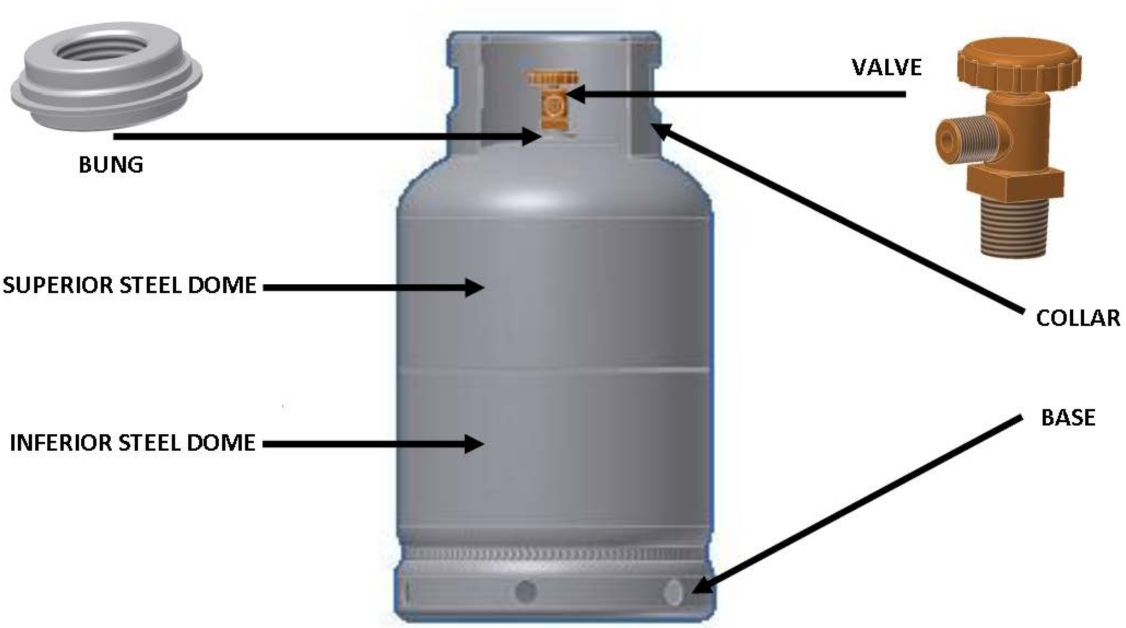

Figure 20 – Main components of a Steel pressure cylinder (Gomes, 2013)

2.3.5.1 Production flow

The production flow on a pressure steel cylinder manufacturer can vary accordingly to the company state of the art. The following chart describes briefly a production flow from a company, market leader in this sector, AMTROL-ALFA part of the Worthington Industries group:

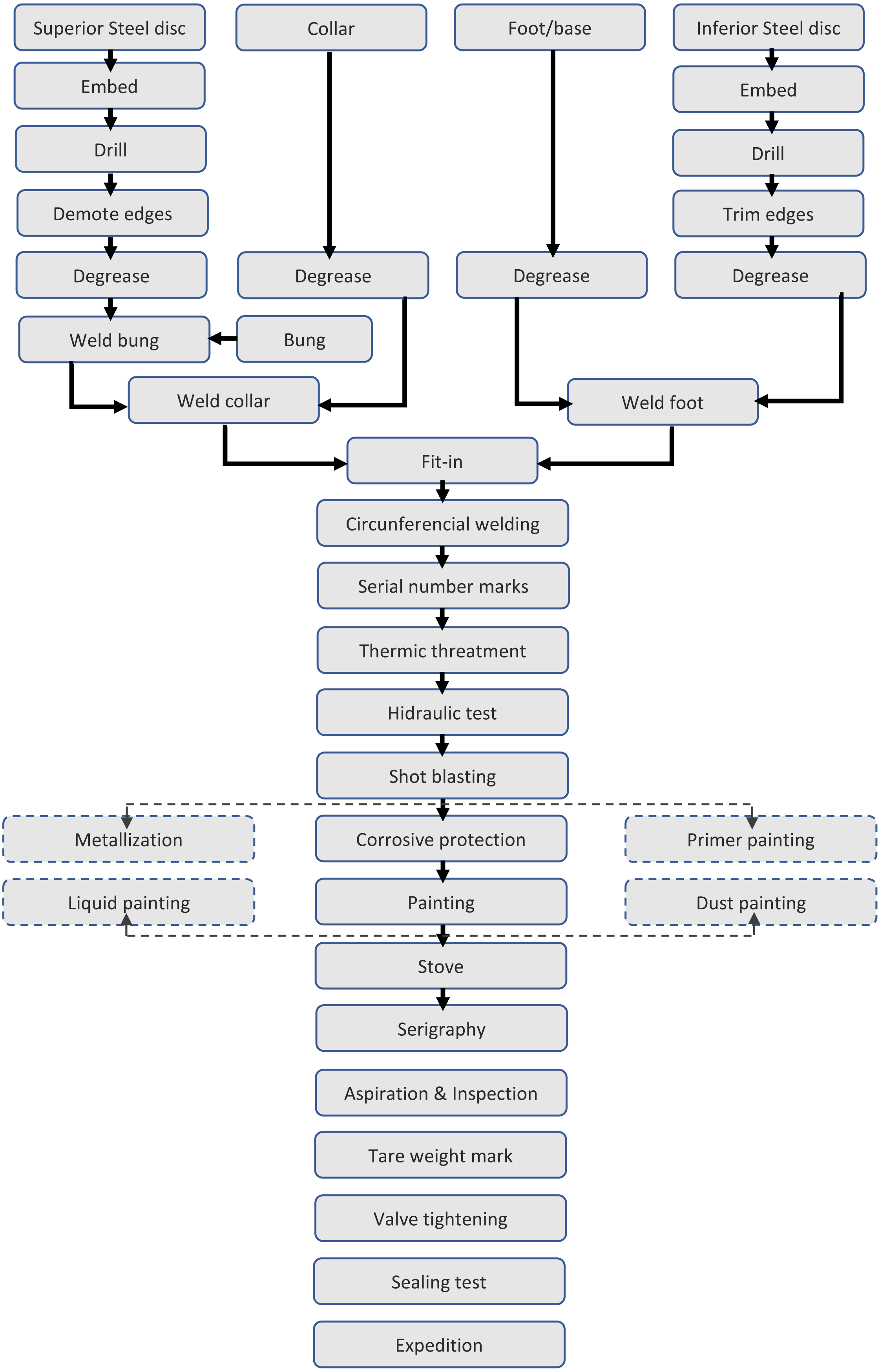

Figure 21 - LPG Steel cylinder production flow

2.3.5.2 Main processes

Sheet-metal cutting – The main parts of the cylinder are the collar, foot and body. All these components provide from an initial cutting process. Steel is received from the supplier in sheet-metal coils, that can go up to 20 tons. The cutting is made by a mechanical press, creating steel discs to be used for the cylinder body, or steel ribbons to make the collar and cylinder foot.

Mechanical conformation –Conformation process occurs using the cutting discs, where a hydraulic press is used to give a shell shape (one for the top, another for the bottom of cylinder body). It is important to refer that, in each of the top or bottom shell, additional adds are made. The top shell requires a second process (in some cases during the embedding step), a puncture to create the valve hole and the bottom shell may require an additional shape, depending on models.

Welding – After the shells are cleaned and placed in together, they are submitted to a circular welding. The welding process used is the submerged arc welding, but depending on the cylinder models, steel thickness, pressure and standards required, other processes can be used. In the collar and foot welding process, is used a Gas Metal Arc Welding (GMAW).

Heat treatment – After the welding and mechanical processes on each component of the cylinder, the materials have suffered tensions modifying their properties. Therefore, the cylinder needs to be submitted to a heat treatment at around 900 °C in the oven, to relieve residual stresses and recover material properties - annealing process.

Hydraulic test – A fugacity test is required on 100% of the cylinders. All cylinders are pressurized with water up to the test pressure (defined by regulation accordingly to cylinder type). Any sign of humidity outside of the cylinder may indicate a leak and therefore is rejected. A dry process is required after the test. Some cylinders are instead submerged under water, after they have been pressurized with air. If any bubbles are seen in the tank, the cylinder is rejected.

Shot blasting – A shot blasting is projected against the cylinder to prepare a surface for the finishing process.

Corrosive protection – There are two optional processes depending on cylinder use or customer requirements. In one of the processes, it is used a primarily painting by spray, when a powder coating paint is required. The other process, when the finishing is made using a liquid paint, requires a previous metallization primary, using an electric zinc arc spray.

Painting – After the corrosive protection is done, the next step is the finishing. The painting can be done by spray or electrostatic powder. The electrostatic powder is a better option when a higher shock resistance is required.

Finishing/Inspection – At the end of the line, a rectification is done to the valve thread, to assure a good connection with the valve. An aspiration of the interior is done, to assure no impurities cause any reaction or bad functioning. A final inspection is made to 100% of the cylinders.

Markings – After the cylinder is manufactured, inspected and approved for sale, it should be marked with their weight, adding the valve weight added later.

2.3.6 Composite cylinders

One of the most innovative companies in the steel cylinder sector – AMTROL ALFA – launched new composite models into the market, causing a disruption to the traditional classic steel cylinders. Despite company core business was to transform steel, this project required audacity by introducing a relevant composite part on the new cylinder construction.

Figure 22 – Components of the COMET® cylinder (Vieira *et al.*, 2010)

The new technology allowed to balance the exigent safety requirements imposed by regulation, and the consumer demand for a modern and convenient product where weight and ergonomics were mandatory for consumer satisfaction.

	COMET				COMET XD	
HEIGHT mm	404	507	549	582	542	570
DIAMETER mm	310	310	310	310	320	320
WATER CAPACITY L	12,5	19,1	22	24	24	26,2
TARE WEIGHT kg	4,9	6,2	6,8	7,2	7,2	7,5
BUTANE kg	6	9	11	12	12	13
PROPANE kg	5	8	9	10	10	11
VALVES	Suitable for all types	Suitable for all types	Suitable for all types	Suitable for all types	Suitable for all types	Suitable for all types

Figure 23 – COMET® product range (AMTROL-ALFA, 2018)

Figure 24 - Composite cylinder construction COMET® (AMTROL-ALFA, 2018)

Different types of fibers and coating can be applied to different gas types, and pressures. The new winding process and fiber type are also adapted to the specific requirements of each market and regulation.

2.3.6.1 Production flow

With the composite models, several changes occurred such as new components, new materials, new processes, new logistic requirements, etc. The COMET® is one of the common models launched, that will be used as a reference for the present study.

The new composite models required a deep change on the production area and technology. Despite part of the composite cylinders are made with steel domes using the traditional processes, the composite parts and final assembly, required a new and dedicated plant.

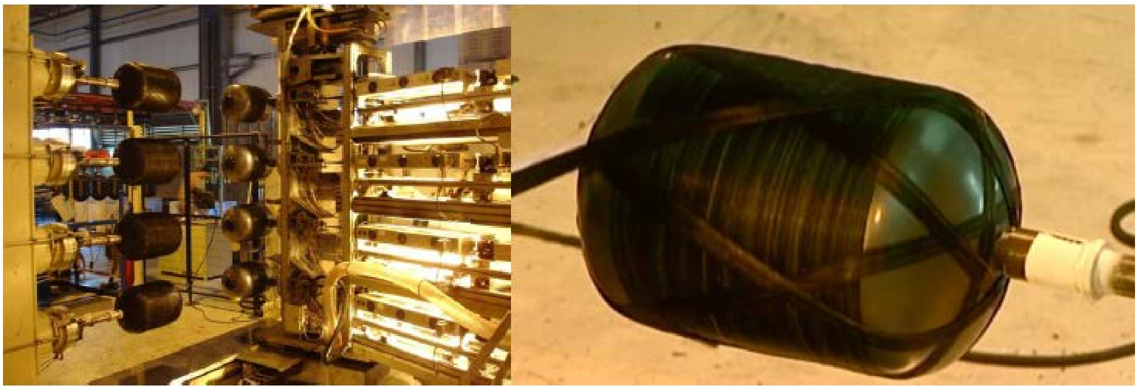

Figure 25 - The thermoplastic winding machine (Gomes, 2013)

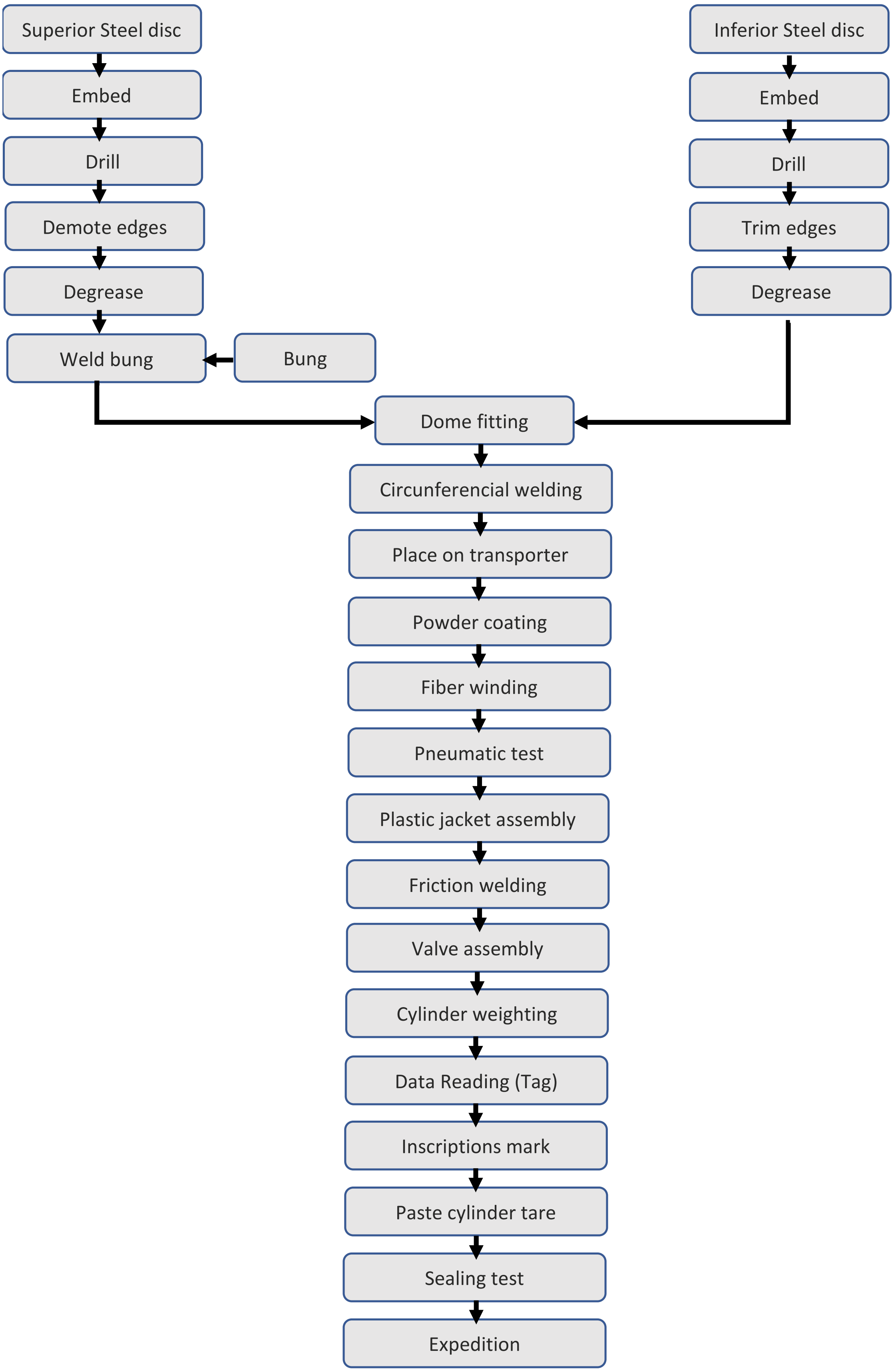

Figure 26 - LPG Composite cylinder production flow

2.3.6.2 Main processes

The processes are very similar to the steel cylinder, using different (thicker) steel sheet, until the painting process (Sheet-metal cutting, Mechanical conformation, Welding, Heat treatment, Hydraulic test, Shot-blasting, Corrosive protection (using polymeric thermoplastic by powder coating). The new processes were:

Winding – After the coating protection is applied, the winding process for fiber enrolment is required. Different fibers can be used accordingly to model.

Pneumatic test – the cylinder, after fiber enrolment, is submitted to an air-pressure test, to find any potential leaks or deformations.

Plastic jacket assembly – The inner part, formed by steel and fiber, is now placed inside a High-density Polyethylene (HDPE) jacket, where an additional padding, assures the perfect fit.

Friction welding – The HDPE jacket is closed, using a friction welding process.

Valve assembly – The valve is assembled with specific torque and position.

Cylinder weight and data register –The cylinder is weighted, and all registers are recorded on an electronic tag, attached to the interior of the jacket.

Leaking test – a final test is made assuring that there is no leaking from the cylinder or valve fit.

Markings – After the cylinder is manufactured, inspected and approved, it is marked on the bottom with the mandatory marks.

2.3.7 Logistics

2.3.7.1 Packaging

The gas industry is mostly considered as a commodity market; therefore, all marginal costs should be kept into the minimums. Depending on the gas type, the packaging can be adapted accordingly to market needs, or to logistic convenience. The LPG (Liquefied petroleum gas), also commonly referred as simply propane or butane, has several limitations to the product sizing and packaging, such as regulation, volume/gas demanded by consumers, gas companies' connectors and storage facilities, distribution trucks and cells, etc.

With other gases and markets, such as helium for recreation (balloons inflation) use, the gas type is less dangerous and therefore more flexible to adapt to different cylinder types. The helium consumer market is less regulated and standardized. In this case is possible to adapt cylinder sizes and shapes, to better fit full truck and containers, lowering freight costs and environmental impact at the same time, by optimizing transport use.

2.3.7.2 Restrictions

The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) (United Nations, 2015), or the International Maritime Dangerous Goods (IMDG) is the legal manuals, guiding the industry on the classification and transport of dangerous goods. These regulations also establish the maximum of product (gases in this case) that can be shipped either in truck or container. The safety requirements for each case, are also described in these publications.

The volume and shape of the cylinders should consider not only the transport from the cylinder manufacturers to the gas company, but also (especially) the legal requirements and limitations during the transport of the cylinder on its lifecycle, with the gas content.

2.3.7.3 Optimization versus transportation restrictions

Most part, if not all the pressurized cylinders, have a circular shape for several reasons (manufacturing process, assuring steel mechanical properties uniform, gas stability requirement etc.). This aspect obviously will result in a loss of space during transport or storage. An ideal scenario from simplistic and logistic view, even if illusional for the most part of gases with today's technology, would be squared cylinders to perfectly fit together and avoid empty spaces in a truck or container load. Not being possible with today's reality, the vertical stacking is a key focus of the logistic optimization process.

Most part of the small and commonly used LPG cylinders (residential use), are designed assuring that collar fits the base of a stacked cylinder. The collar part needs to assure ergonomic, strength to support vertically several filled cylinders over it and protect the valve from impacts. By the other side, the cylinder base is conceived to provide stability to the cylinder, protect cylinder body from impacts, and assure a perfect connection to the collar of an under-stack cylinder assuring good vertical stability. At the same time, it must use the minimum material required to comply with its service.

Industrial gas cylinders are not traditionally overstock, being transported in dedicated metal cages. Requirements are strict from the safety side, using sometimes special types of transport, adapted to the specific use only.

DEVELOPMENT

3.1 CASE STUDY
3.2 ECO-DESIGN TOOL SELECTION
3.3 LIDS WHEEL MODEL IMPLEMENTATION
3.4 LIDS WHEEL MODEL RESULTS
3.5 RESULTS INTERPRETATION
3.6 RESULTS VALIDATION

3 DEVELOPMENT

An eco-design approach will be applied to analyse the environmental impact, when switching from a traditional steel-only cylinder, to an equivalent composite + steel type of cylinder. The composite + steel will be referred to just as “composite” type. Both models are manufactured at AMTROL-ALFA company located in Portugal, worldwide leader as pressure cylinders manufacturer.

3.1 Case study

The chosen models are the traditional **LPG steel 26.2 L** steel cylinder, and the **COMET® 24L** composite + steel cylinder technology. These models are very common in the residential market, therefore, any impact with a replacing product, will have a significant result (Plouffe *et al.*, 2011). The models’ size is considered equivalent, since these cylinders have approximately the same dimensions, which is one of the key factors for any gas distributor to keep compatibility of their equipment and distribution tools, despite the slight reduction of gas content.

In TABLE 1 and TABLE 2 below, there is the dimensional characterization of both models:

TABLE 1 - COMET 24L (AMTROL-ALFA, 2018)

COMPOSITE CYLINDER DIMENSIONS	#
HEIGHT [mm]	582
DIAMETER [mm]	310
WATER CAPACITY [L]	24
TARE WEIGHT [Kg]	7.2
BUTANE [Kg]	12
PROPANE [Kg]	10
VALVES	Suitable for all

TABLE 2 - LPG Steel Cylinder 26,2L (AMTROL-ALFA, 2018)

STEEL CYLINDER DIMENSIONS	#
HEIGHT [mm]	580
DIAMETER [mm]	300
WATER CAPACITY [L]	26.2
TARE WEIGHT [Kg]	15,3
BUTANE [Kg]	13
PROPANE [Kg]	12

VALVES	Suitable for all

To proceed with the comparison, it is necessary to go through the following steps:

- Define the eco-design tool;
- Gather the necessary information from both models;
- Build-up the model and evaluate;
- Interpret results.

3.2 Eco-design tool selection

The scope of this report is to analyse and reach a conclusion about the switch from a traditional steel cylinder, to a new technology composite and steel cylinder. Between the referred eco-design tool and models, the LiDS Wheel was chosen due to the characteristics of the model, information available and the fact that two models are compared to evaluate environmental impacts.

"Because the LiDS Wheel Analyses are inherently qualitative, and based on an arbitrarily defined system of evaluation, it is not a method that can be used to determine the actual environmental impact of a product. It is, however, an excellent method for evaluating environmental trade-offs between two similar or evolutionary designs" (Solidworks, 2018).

The following strategies will be analysed and evaluated, using the specific criteria defined by the model (Behrisch *et al.*, 2011), (Agudelo, 2017).

- ✓ New concept development;
- ✓ Selection of low-impact materials;
- ✓ Reduction of material usage;
- ✓ Optimization of production techniques;
- ✓ Optimization of the distribution system;
- ✓ Reduction of environmental impact during use;
- ✓ Optimization of the initial lifetime.

The detailed interpretation of the strategies and criteria are described in ANNEX I in 6.1.

A scale will be used on each subjective evaluation, where:

1 – Very bad   2 – Bad   3 - Acceptable   4 - Good   5 – Very good

The result will allow understanding the environmental impact. The higher is the area of the geometric shape, the lower impact it has on the environment, therefore, eco-friendlier.

3.3 LiDS wheel model implementation

3.3.1 New concept development

This strategy is based on the following criteria evaluation: Dematerialization, share use of the product, integration of functions and functional optimization of product/components.

3.3.1.1 Dematerialization

On dematerialization, it is wondered if the consumer needs in fact the physical product, or if somehow it can be replaced by a service.

In the gas sector, the service provided is the gas supply and cylinder rent. But cylinders as product, is not possible to be dematerialized into a service.

TABLE 3 - Dematerialization criteria evaluation

Steel Cylinder	Composite Cylinder
Product characteristics do not allow a dematerialization.	Product characteristics do not allow a dematerialization.
1 - (Very bad)	**1 - (Very bad)**

3.3.1.2 Shared use of the product

The product share is about the common use with others. Whether it requires to be a single user type or several users, the ownership importance may define the product on these criteria.

The product is used by a single filling company, but it can be re-filled for several different consumers, which does not require a specific cylinder for each consumer.

TABLE 4 - Shared of product criteria evaluation

Steel Cylinder	Composite Cylinder
The same product can be re-used and shared several times, since the business model is to rent or deposit	The same product can be re-used and shared several times, since the business model is to rent or deposit
4 - (Good)	**4 - (Good)**

3.3.1.3 Integration of functions

What evaluates the product in these criteria is how the product consolidates in one (or few) products, the functions of several others.

Not many features are consolidated in one gas cylinder, but some improvements were made to the electronic register and track of cylinders.

TABLE 5 - Integration of functions criteria evaluation

Steel Cylinder	Composite Cylinder
The only function is the gas content.	Besides the gas function, the Comet has a tag that allows the gas companies, to track and control refill and lifetime.
3 - (Acceptable)	**4 - (Good)**

3.3.1.4 Functional optimization of product/components

The optimization of the components occurs when they can be combined in different models, instead of having totally different components for each model, generating inefficiencies. Modular products generate savings and efficiencies on stock management and processes improvement.

TABLE 6 - Functional optimization of product/component criteria evaluation

Steel Cylinder	Composite Cylinder
Cylinder domes can only be used in few model types. On the other hand, collar and base/foot can have multiple applications.	Composite cylinders have more components than the traditional steel cylinders, but most parts are used in several different models. Many combinations can be done using common parts.
3 - (Acceptable)	**4 - (Good)**

3.3.2 Selection of low-impact materials

This strategy bases its success through the following criteria assessment: cleaner materials, renewable materials, lower energy content materials, recycled materials and recyclable materials.

3.3.2.1 Cleaner materials

Clean materials are the ones that do not cause any harm or emissions to the environment, therefore, the preferred ones to be used. Even though the material selection is a focus, the production process of the cylinders may require the additional use of consumables that may compromise the material selection as shown in TABLE 7:

TABLE 7 - Materials and consumables used during production (Gomes, 2013)

MATERIALS	STEEL CYLINDER	COMPOSITE CYLINDER
Paper/Carton	✓	✓
Plastic	✓	✓
Wood	✓	✓
Hydraulic oil	✓	✓
Steel	✓	✓
High-density polyethylene (HDPE)		✓
Composite (polypropylene + fiber glass)		✓
Zinc (for metallization)	✓	
Solvent-based paints	✓	
Welding consumables	✓	

Industrial products used in the production of steel cylinders like hydraulic oil, solvent-based ink sludges, cleaning solvents, contaminated recipients, contaminated absorbents, revealing and fixing baths, can cause serious damage to the environment.

With the composite cylinder, many dangerous products were avoided by using this new technology. This is clearly an improvement on environmental impact.

TABLE 8 - Cleaner materials criteria evaluation

Steel Cylinder	Composite Cylinder
Some of the industrial consumables used during production are considered dangerous to the environment.	The composite cylinders manufacturing technology reduces many of the dangerous products used on the traditional steel cylinders.
1 - (Very bad)	**3 - (Acceptable)**

3.3.2.2 Renewable materials

The renewable materials on the product are relevant to know how the final product is consuming non-renewable resources. Renewable materials are "resources that can or will be replenished naturally at the same pace, or faster, than it is consumed" (Patay, 2009) (Maio *et al.*, 2017).

The steel cylinders are not using renewable materials on its construction, neither composite cylinders.

TABLE 9 - Renewable materials criteria evaluation

Steel Cylinder	Composite Cylinder
No renewable materials in the cylinder construction.	No renewable materials in the cylinder construction.
1 - (Very bad)	**1 - (Very bad)**

3.3.2.3 Lower energy content materials

Some material requires high levels of energy to be produced. Alternative products, with less energy required, would be an advantage.

The steel is the product that represents the biggest share of the product and by far the one that requires the higher level of energy to be produced, as indicated in TABLE 10.

TABLE 10 - Materials and energy required for cylinder construction (Vieira, 2010; Gomes, 2013)

MATERIALS	MMBT/ton	STEEL CYLINDER	COMPOSITE CYLINDER
Steel (including scrap) (Hasanbeigi *et al.*, 2011)(U.S. Environmental Protection Agency, 2007)	19.00	17.00 kg	4.50 kg
HDPE (Tsiamis *et al.*, 2016)	19.50		1.80 kg
Composite (FG+PP) (Dai *et al.*, 2015)	3.70		1.50 kg
Total Consumption (MMBtu x Weight)		0.323 MMBtu	0.134 MMBtu

Thus, the composite cylinders technology was able to reduce the use of energy by approximately 60%. Despite composite cylinders use an internal steel liner, the thickness and weight are substantially lower. The energy consumption of each material was collected from the literature.

TABLE 11 - Lower energy content materials criteria evaluation

Steel Cylinder	Composite Cylinder
Steel industry requires an intensive use of energy. The classic cylinders are mostly constituted by steel.	Composite cylinders use steel, but in less quantity when compared with traditional ones. Despite the other products like fiberglass or HDPE have a considerable energy consumption during its production, the energy saving is almost 60%.
1 - (Very bad)	**3 - (Acceptable)**

3.3.2.4 Recycled materials

The use of recycled materials can reduce the environmental impact of products.

The cylinder construction is submitted to exigent mechanical properties, that need to be uniform along the whole material. Recycled steel is used, as long as it complies with the required properties.

TABLE 12 - Recycled materials criteria evaluation

Steel Cylinder	Composite Cylinder
Steel cylinder is made of recycled steel	The steel content in the composite cylinder is also recycled. Most parts of the other components are not eligible to introduce recycled materials.
5 - (Very good)	**4 - (Good)**

3.3.2.5 Recyclable materials

Despite recyclable products may not be used in the product construction, it is possible to use materials that can be recycled and re-used afterward.

As described before, the selection of materials was done based on the environmental impact. Anyway, the transformation of each one of the materials, may change product characteristics or require the use of consumables. During the steel cylinders production, the materials used for construction and transformation, will have the following destiny as described in TABLE 13:

TABLE 13 - Materials and consumables used in steel cylinders construction (Gomes, 2013)

MATERIALS USED IN STEEL CYLINDERS PRODUCTION (DISPOSABLE)	CLASSIFICATION	FINAL DESTINY
Paper/Carton	Valuable	Recycling
Plastic	Valuable	Recycling

Wood	Valuable	Recycling
Hydraulic oil	Dangerous	Co-incineration
Steel scrap	Valuable	Recycling
Steel-shot powder	Valuable	Recycling
Zinc powder	Valuable	Recycling
Solvent ink mud	Dangerous	Co-incineration
Solvent-based paints	Dangerous	Regeneration
Welding scrap	Inert	Landfill
Contaminated packages	Dangerous	Co-incineration
Contaminated absorbers	Dangerous	Co-incineration
Baths of revelation and fixation	Dangerous	Co-incineration
Radiographic films	Valuable	Recycling

On the Composite cylinders, some of the following materials used can be recycled, co-incinerated or given other uses, as indicated in TABLE 14:

TABLE 14 - Materials used in composite cylinders construction (Gomes, 2013)

MATERIALS USED IN COMPOSITE CYLINDERS PRODUCTION (DISPOSAL)	CLASSIFICATION	FINAL DESTINY
Paper/Carton	Valuable	Recycling
Plastic	Valuable	Recycling
Wood	Valuable	Recycling
Hydraulic oil	Dangerous	Co-incineration
Steel scrap	Valuable	Recycling
High-density polyethylene (HDPE)	Valuable	Recycling
Composite (polypropylene + fiber glass)	Sub-product	Other uses (Asmatulu *et al.*, 2014)*

Despite there is always space for improvement, there was a clear reduction of waste and impact, with the new composite technology.

TABLE 15 - Recyclable materials criteria evaluation

Steel Cylinder	Composite Cylinder
The used steel for cylinder manufacture has very good quality. This steel can be easily recycled and used on several applications where mechanical properties are not so exigent.	Most part of the materials used on the composite cylinders can be recycled. Steel, plastic, fibers can be reprocessed and used in less exigent products (Asmatulu, 2014).
5 - (Good)	**4 - (Good)**

3.3.3 Reduction of material usage

This strategy bases its success through the following criteria assessment: Reduction in weight and Reduction in volume.

3.3.3.1 Reduction in weight

The capacity for offering the same product and performance with less weight is a relevant argument that can generate several environmental benefits or mitigate negative impacts.

In TABLE 16 is possible to see that steel cylinders use around 17 kg of steel on its construction, generating an end-product of 15.25 kg.

TABLE 16 - Materials weight per model (Gomes, 2013)

MATERIALS	STEEL CYLINDER	% of total	COMPOSITE CYLINDER	% of total
Steel needed (excluding scrap)	15.25 kg	99.70%	3.70 kg	51.40%
High-density polyethylene (HDPE)			1.80 kg	25.10%
Composite (polypropylene + fiberglass)			1.50 kg	20.80%
Powder paint (Thermoplastic + zinc)			0.20 kg	2.70%
Solvent-based paint	0.05 kg	0.30%		
Total	15.30 kg	100%	7.20 kg	100%

Using the composite technology, the steel use is reduced drastically to 4,5 Kg of steel, generating 3,70 kg in the final product after the scrap. The other materials weights are also relevant but less expressive.

The weight reduction will contribute to a CO_2 reduction during freight. If one considers the following assumption to calculate CO_2 savings: *"The average CO_2-emission factor recommended by McKinnon for road transport operations is 62g CO_2/tonne-km. This value is based on an average load factor of 80% of the maximum vehicle payload and 25% of empty running"* (ECTA, 2011). The number of cylinders per truck is 835 units (for both models) as per AMTROL manufacturer information:

Steel cylinders: 835 units x 15,30 kg = 12.776 ton x 62 gCO_2/ton-km = 792.11 gCO_2/km

Composite cylinders: 835 units x 7.2 kg = 6,012 ton 62 gCO_2/ton-km = 360.72 gCO_2/km

The weight reduction on each truck is around 6,764 ton per truck (considering empty cylinders), which would represent (792.11 – 360.72) = 431.39 g of CO_2 emissions savings per km (less 57%).

TABLE 17 - Reduction in weight criteria evaluation

Steel Cylinder	Composite Cylinder
End-product weight: 15.3 kg With the traditional steel technology, weight is a negative issue, from the consumer perspective,	End-product weight: 7.2 kg The new composite technology allows to deliver similar product, with much less weight when

but also from the logistic requirements.	compared with traditional steel models (around 50% reduction). Not only the weight reduction is a great benefit for consumers, but also, the impact on CO_2 emission reduction is massive.
2 - (Bad)	**5 - (Very good)**

3.3.3.2 Reduction in volume

The volume reduction in optimizing the transport, is a key factor when savings are required, not only from the cost perspective, but also for the environmental impact. The same logic as per weight savings, volume reduction would generate benefits by transporting more quantity with less energy and emissions per unit.

Despite the advantages, and considering the models choice assumptions, the gas market requires an equivalent sizing model to fit their existing logistic infrastructure. The TABLE 18 shows height and diameters of both models.

TABLE 18 - Steel and Composite cylinders dimensions (AMTROL-ALFA, 2018)

MATERIALS	STEEL CYLINDER	COMPOSITE CYLINDER
Height	580 mm	582 mm
Diameter	300 mm	310 mm

Therefore, considering the sizes of the different models, there are no significant differences on sizing.

TABLE 19 - Reduction in volume criteria evaluation

Steel Cylinder	Composite Cylinder
The steel cylinder can handle 26.2 Liters (water capacity). The fact that the cylinder is only made of steel, it allows to maximize water capacity volume.	The outside volume of the composite cylinder, when similar to the classic steel alternative, reduces the product performance (gas content) from 26.2 Liters to 24 Liters (water capacity). For the same content as steel cylinder, it would require more volume.
4 - (Good)	**3 - (Acceptable)**

3.3.4 Optimization of production techniques

This strategy bases its success through the following criteria assessment: alternative production techniques, fewer production steps, lower and cleaner energy consumption, fewer production wastes and fewer/cleaner production wastes (de Aguiar, 2017).

3.3.4.1 Alternative production techniques

During the production process, alternative techniques should be applied to minimize environmental negative impacts.

The water treatment for re-use is a positive technique to minimize the use of this resource. On the energy side, efficient equipment is preferred, reducing energy or gas consumption.

The painting process is also focused on a technique to minimize impact. This technique used in the process assures that, the excessive powder projected drops into a vessel, from where is vacuumed up again to the machine powder storage to be re-used. The equipment has 98% efficiency (Vieira, 2010), therefore, emissions are limited to 2%.

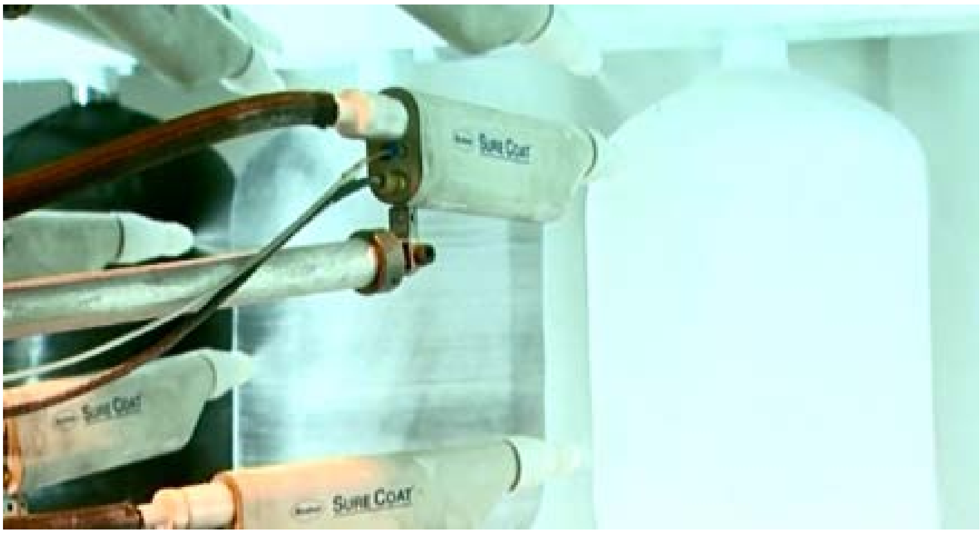

Figure 27 - Polymeric coat on COMET cylinder (Gomes, 2013)

On the steel cylinder model, painting is still done using a liquid paint, where some losses are verified, through the evaporation or by missing the target. One of the main advantages is the minimum paint loss, and the re-use of drop excesses. This technique is more efficient than liquid paint, where losses can achieve the 40%.

TABLE 20 - Alternative production techniques criteria evaluation

Steel Cylinder	Composite Cylinder
Steel cylinders have some techniques in place to save energy and reduce emissions and waste, but there is still space for improvement. Ex. Using electrostatic painting, to reduce waste.	The composite technology allows to use softer techniques to reduce environmental impact, but also fewer materials consumption, reducing waste and energy. It requires though, to add the pigment and zinc used on the polymeric-matrix coating.
3 - (Acceptable)	**4 - (Good)**

3.3.4.2 Fewer production steps

The reduction of steps during production can revert in significant savings in time-consuming, but also on potential emissions.

The composite technology may require more steps than the traditional steel cylinders, but both production lines look quite optimized.

TABLE 21 - Fewer production techniques criteria evaluation

Steel Cylinder	Composite Cylinder
Production techniques and steps quite optimized, but in process of permanent improvement.	Production techniques and steps quite optimized, but in process of permanent improvement.
3 - (Acceptable)	**3 - (Acceptable)**

3.3.4.3 Lower and cleaner energy consumption

Cleaner and lower consumption methods should be available.

On the welding process, to choose the right process for the model and application, it can revert in a relevant energy saving. The composite model uses a pulsed arc on the circumferential welding, that reduces energy consumption by 40% when compared to the conventional MAG welding used in the steel cylinder. On the other hand, the winding process and the required heating to conform material, increase the electric energy consumption to levels slightly over the steel model needs in 7,7%, as shown in TABLE 22:

TABLE 22 - Energetic consumption, per model type (Gomes, 2013)

ENERGETIC CONSUMPTION	STEEL CYLINDER	COMPOSITE CYLINDER
Electric	3.25 kW/unit	3.45 kW/unit
Natural Gas	1.00 m^3/unit	0.16 m^3/unit

On the gas evaluation, the need of the composite model is considerably lower, reaching an 84% saving.

TABLE 23 - Lower and cleaner energy consumption criteria evaluation

Steel Cylinder	Composite Cylinder
Steel cylinder has a high level of energy consumption, difficult to revert, due to materials and process characteristics.	The use of the winding machine requires a lot of electric energy (more 7.6%), but this technology reduces drastically the gas use (less 84%), which is a good step by reducing costs and emissions.
3 - (Acceptable)	**4 - (Good)**

3.3.4.4 Less production wastes

The waste is by principle a cost for the company, but also a cost for the environment. To reduce it or re-use the waste, is a plus.

The waste of most relevant material – steel – on the traditional cylinders is around 1.9 kg per unit produced. The steel waste on the composite type, is around 0.8 kg per unit produced.

Regarding other wastes are hard to obtain the amount disposed, but the description of wastes allows to issue some conclusions in TABLE 24:

TABLE 24 - Materials used and disposed on models' production (Gomes, 2013)

MATERIALS USED AND DISPOSED ON STEEL CYLINDERS PRODUCTION	MATERIALS USED AND DISPOSED ON COMPOSITE CYLINDERS PRODUCTION
Paper/Carton	Paper/Carton
Plastic	Plastic
Wood	Wood
Hydraulic oil	Hydraulic oil
Steel scrap	Steel scrap
Steel-shot powder	High-density polyethylene (HDPE)
Zinc powder	Composite (polypropylene + fiberglass)
Solvent ink mud	
Solvent-based paints	
Welding scrap	
Contaminated packages	
Contaminated absorbers	
Baths of revelation and fixation	
Radiographic films	

TABLE 25 - Less production wastes criteria evaluation

Steel Cylinder	Composite Cylinder
Wastes caused by steel cylinder process is high, basically on steel that represents the biggest share.	New technology allows to reduce the waste of the main material, steel. The remaining materials are 100% used or almost.
3 - (Acceptable)	**4 - (Good)**

3.3.4.5 Fewer/cleaner production consumables

The methods and techniques referred, have focused on using the right strategy for production. Reduce effects from consumables is important to reduce production negative impact on the environment.

Information about the emissions and wastes from the production was collected. The main processes analysed were the embedding, washing, welding, painting and exhausting. The industrial effluents indicate the water used in the process, the total treated water and returned to the system and the non-reusable water, resulted from the process as described in TABLE 26.

TABLE 26 - Industrial effluents, per model type (Gomes, 2013)

INDUSTRIAL EFFLUENTS	STEEL CYLINDER PROCESS	COMPOSITE CYLINDER PROCESS
Water collected	0.0255 m^3/unit	0.02 m^3/unit

Returned water	0.0096 m³/unit	0.0075 m³/unit
Total residual water	**0.0159 m³/unit**	**0.0125 m³/unit**

The washing tank (WT) has some drying burners, that cause emissions. Steel cylinders process require the use of two washing tanks. The parameters and evaluation shown in TABLE 27 include the total emissions:

TABLE 27 - Gaseous emissions on washing tanks per model type (Gomes, 2013)

GAS EMISSIONS WASHING TANK	PARAMETERS	UNITS	COMPOSITE CYLINDER	STEEL CYLINDER WT #10	STEEL CYLINDER WT # 11
BURNER 1, 2, 3	NOx	mg/Nm³	243	245	275
	COV's	mgC/Nm³	61	68	39

During the welding process, the equipment releases particles emissions. The steel cylinder, due to steel type and thickness requires a more intense welding process (submerged arc welding) when compared to the composite cylinder using a MIG/MAG welding process. The released particles are described in TABLE 28:

TABLE 28 - Gas emissions on welding process, per model type (Gomes, 2013)

GAS EMISSIONS WELDING	PARAMETERS	UNITS	COMPOSITE CYLINDER	STEEL CYLINDER	LEGAL LIMIT
PROCESS	PARTICLES	mg/Nm³	10	21	150

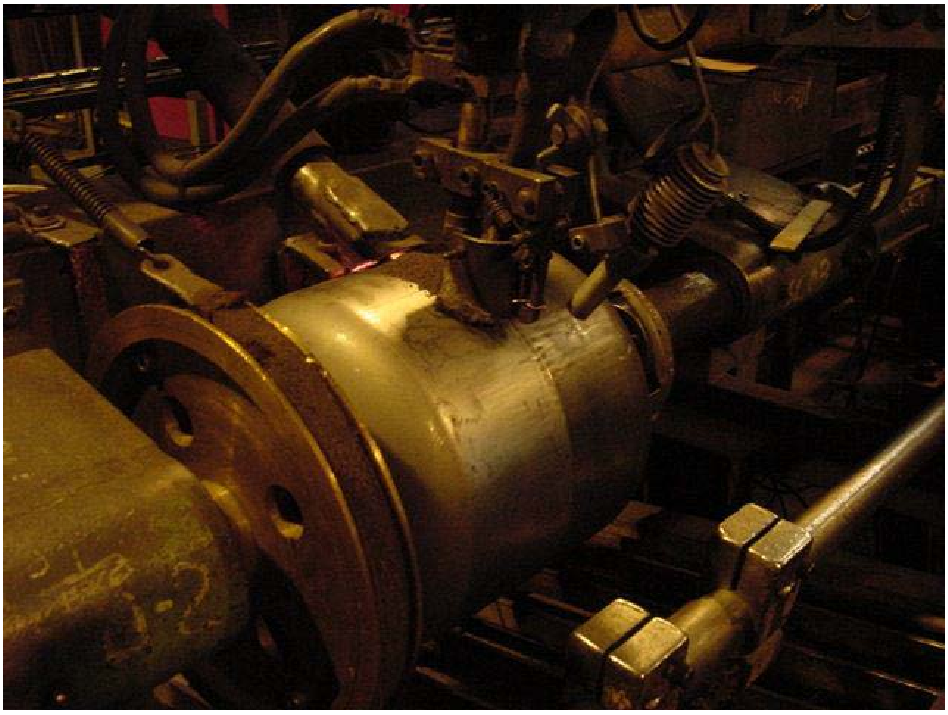

Figure 28 - Circumferential welding process - submerged arc welding (Gomes, 2013)

The painting and drying process is one of the main processes to analyse, when an environmental impact assessment is made. In TABLE 29, are described the emissions during the painting and drying process of the steel cylinders manufacturing process:

TABLE 29 - Gas emissions from painting line - Steel cylinder (Gomes, 2013)

GAS EMISSIONS PAINTING	PARAMETERS	UNITS	STEEL CYLINDER	LEGAL LIMIT
Cabin #1	NOx	mg/Nm³	81	150
	COV's	mgC/Nm³	1892	75
Tunnel #1	NOx	mg/Nm³	5	150
	COV's	mgC/Nm³	270	75
Cabin #2	NOx	mg/Nm³	32	150
	COV's	mgC/Nm³	1265	75
Tunnel #2	NOx	mg/Nm³	20	150
	COV's	mgC/Nm³	218	75
Cabin #3	NOx	mg/Nm³	17	150
	COV's	mgC/Nm³	369	75
Tunnel #3	NOx	mg/Nm³	21	150
	COV's	mgC/Nm³	498	75

Figure 29 – Painting line

In the steel cylinder production, the product is submitted to a curing process after the painting, by passing through a curing oven. But In the composite type, the cure is made after the winding of the fibers. The gas emissions are sent to atmosphere through the exhaustion process. This process uses two exhausting systems. Parameters and measured emissions are described in TABLE 30:

TABLE 30 - Gaseous emissions from an exhaust system of cure oven, per model type (Gomes, 2013)

GAS EMISSIONS CURE OVEN	PARAMETERS	UNITS	COMPOSITE CYLINDER	STEEL CYLINDER	LIMITS
Exhaustion #1, #2	COV's	mgC/Nm^3	17	2231	50

Also, within the curing process, the used burners are causing emission as described in TABLE 31:

TABLE 31 - Gaseous emissions from burners of cure oven, per model type (Gomes, 2013)

GAS EMISSIONS CURE OVEN	PARAMETERS	UNITS	COMPOSITE CYLINDER	STEEL CYLINDER	LIMITS
Burner #1, #2	NOx	mg/Nm^3	60	102	500
	COV's	mgC/Nm^3	180	173	200

The cleaning and preparation process of the cylinders through a metal-shot process, send some particles to the atmosphere as described in TABLE 32:

TABLE 32 - Gas emissions from shot steel equipment - Steel cylinders (Gomes, 2013)

GAS EMISSIONS SHOT STEEL	PARAMETERS	UNITS	STEEL CYLINDER LINE
PROCESS	PARTICLES	mg/m^3	132

The heating process to relieve stresses from the steel and re-establish the expected mechanical properties, has also an impact on emissions as described in TABLE 33:

TABLE 33 - Gaseous emissions from heating treatment equipment - Steel cylinders (Gomes, 2013)

GAS EMISSIONS HEATING TREATMENT	PARAMETERS	UNITS	STEEL CYLINDER LINE
BURNER 1	NOx	mg/Nm^3	5
	COV's	mg/Nm^3	10

TABLE 34 - Fewer/cleaner production consumables criteria evaluation

Steel Cylinder	Composite Cylinder
Steel cylinders process has an under-control level of emissions. The values are within limits defined by authorities.	The composite type brought an additional advantage of having less emissions, way below the traditional steel cylinders.
3 - (Acceptable)	**4 - (Good)**

3.3.5 Optimization of distribution system

This strategy bases its success through the following criteria assessment: Less/cleaner/reusable packaging, Energy efficient transport mode and Energy efficient logistics.

3.3.5.1 Less/cleaner/reusable packaging

In the cylinders being analysed, there is no need for external packaging. They both have though, pallets or racks to transport the cylinders. In both cases, these products can be re-used.

TABLE 35 - Less/cleaner/reusable packaging criteria evaluation

Steel Cylinder	Composite Cylinder
No need for packaging	No need for packaging
4 - (Good)	**4 - (Good)**

3.3.5.2 Energy efficient transport mode

To find the right transport can bring not only freight cost advantages, but also optimizes the relation between units shipped and the environmental impact. Both cylinders, having similar dimensions do not differ much on these energy-efficient transport criteria.

TABLE 36 - Energy efficient transport mode criteria evaluation

Steel Cylinder	Composite Cylinder
Steel cylinders are shipped focusing on the	Composite cylinders are shipped focusing on the

optimized volume to transport, complying at the same time with customer requirements.	optimized volume to transport, complying at the same time with customer requirements.
3 - (Acceptable)	**3 - (Acceptable)**

3.3.5.3 Energy efficient logistics

Logistics, as other processes, are under permanent improvement. Reducing product unnecessary movements, is a step forward to save energy and environmental impact.

Regarding the conditioning of the product for freight and storage purposes, both models have similar dimensions, not driving benefits through outer volume as compared in TABLE 37:

TABLE 37 - Logistic information, by model type (Gomes, 2013)

LOGISTIC	PARAMETERS	STEEL CYLINDER	COMPOSITE CYLINDER
WEIGHT	kg	15.30	7.20
DIAMETER	mm	300	310
HEIGHT	mm	580	582
WATER CAPACITY	L	26.2	24

The weight is one of the biggest advantages of the composite technology, reducing it by more than 50%. All the logistic movements along the lifespan of the product, will generate benefits mitigating the CO_2 emissions to the atmosphere (de Aguiar, 2017).

TABLE 38 - Energy efficient logistics criteria evaluation

Steel Cylinder	Composite Cylinder
The shape of the cylinder is built to help logistics, but the weight is a very negative aspect. The steel type of the cylinder requires more refurbishment to keep the aspect and marks, therefore, additional transports.	The shape is comparable to classic cylinders, but the drastic cut on the weight, was a big step on savings. The composite cylinders, due to material characteristics, are less likely to be refurbished, therefore, less cost and energy with these movements.
2 - (Bad)	**4 - (Good)**

3.3.6 Reduction of impact during use

This strategy bases its success through the following criteria assessment: lower energy consumption, cleaner energy source, cleaner consumables and no waste of energy/consumables.

3.3.6.1 Lower energy consumption

Some products require energy consumption to work. The house equipment is a good example on how manufacturers have improved on energy consumption efficiency along the years.

The gas cylinders do not need any electrical power.

TABLE 39 - Lower energy consumption criteria evaluation

Steel Cylinder	Composite Cylinder
Steel cylinder does not need any energy support to provide product service.	Steel cylinder does not need any energy support to provide product service.
5 - (Very good)	**5 - (Very good)**

3.3.6.2 Cleaner energy source

The cleaner source inducts to find a cleaner way to feed energy into the products. The gas cylinders are exempt of this, since they do not need any energy power source to work.

TABLE 40 - Cleaner energy source criteria evaluation

Steel Cylinder	Composite Cylinder
The pressurized gas content provides itself the energy enough to come out of the cylinder and feed the equipment.	The pressurized gas content provides itself the energy enough to come out of the cylinder and feed the equipment.
5 - (Very good)	**5 - (Very good)**

3.3.6.3 Cleaner consumables

Some products require the use of consumables, which sometimes can have a negative impact on the environment when used or disposed (example printers' ink-jets), where the reduction or elimination of consumables use would be positive, however, the gas cylinders are not using any consumable, although it requires a refurbishment from time to time, requiring the change of sealing O-rings which can be considered a consumable.

TABLE 41 - Cleaner consumables criteria evaluation

Steel Cylinder	Composite Cylinder
Almost inexistent use of consumables	Almost inexistent use of consumables
4 - (Good)	**4 - (Good)**

3.3.6.4 No waste of energy/consumables

To change, or reduce, harmful consumables by natural or non-harmful products, can help to reduce the negative footprint of the product use, however, no relevant consumables are used in the cylinders.

TABLE 42 - No waste of energy/consumables criteria evaluation

Steel Cylinder	Composite Cylinder
The consumables are almost inexistent; but the replacing sealings do not allow many alternatives since they need to comply with exigent standards.	onsumables are almost inexistent; but the replacing sealings do not allow many alternatives since they need to comply with exigent standards.
3 - (Acceptable)	**3 - (Acceptable)**

3.3.7 Optimization of initial lifetime

This strategy bases its success through the following criteria assessment: reliability and durability, easier maintenance and repair, modular product structure and classic design.

3.3.7.1 Reliability and durability

The reliability of gas cylinders, have minimums to comply, being regulated under strict regulation. The gas cylinders need to be reliable, otherwise would not be approved for use. Thus, the cylinders have a pre-defined lifetime, defined by regulation (The International Standards Organisation, 2013; Asia Industrial Gases Association, 2014; de Aguiar, 2017). The refurbishment, re-approval, and reintroduction of cylinder in the market are common, which shows a good level of durability.

TABLE 43 - Reliability and durability criteria evaluation

Steel Cylinder	Composite Cylinder
Steel cylinders are being used for many years. Despite being an older technology, is has been showing a good level of reliability.	The composite cylinder is still a recent technology, with proved reliability. But the fact is a new type, does not allow to have firm information about durability.
4 - (Good)	**3 - (Acceptable)**

3.3.7.2 Easier maintenance and repair

The product maintenance and repair require time-consuming and it can generate additional costs, consumables, etc. Both steel and composite cylinders can be refurbished for new use. Anyway, steel cylinder may be simpler to requalify when compared to the composite cylinder.

TABLE 44 - Easier maintenance and repair criteria evaluation

Steel Cylinder	Composite Cylinder
The steel cylinder, if complies with mechanical properties, it only needs to be repainted.	The composite cylinder, when refurbished, may need to replace outer plastic jacket and/or fibers.
4 - (Good)	**3 - (Acceptable)**

3.3.7.3 Modular product structure

The modular replacement of product parts when in repair, can origin savings by reducing spare parts, speeding up service and reduce downtime of the product. Spare parts in the cylinders are limited, but the new composite technology was able to make it part of the process. Some parts are modular and can be used uniformly in different models.

TABLE 45 - Modular products structure criteria evaluation

Steel Cylinder	Composite Cylinder
Spare parts in steel cylinders are very limited, basically, only the valve can be replaced. Collar and cylinder base are eligible to be replaced by a spare part, but it requires accuracy and time-consuming.	The composite cylinder allows a fast repair by replacing damaged parts on its protection jacket, internal protections and valve. An easy intervention can be done without submitting the product to the production line again.
2 - (Bad)	**4 - (Good)**

3.3.7.4 Classic design

The design and product look can be a factor of replacement or refurbishing. Increasing this lifespan, can reduce the number of disposed products or negative impact of requalification.

This topic was much probably one of the most relevant improvements of the new composite technology. Not only the cylinder has a cleaner look as the benefits for the gas distributors are enormous in terms of brand exposure.

TABLE 46 - Classic design criteria evaluation

Steel Cylinder	Composite Cylinder
With the classical steel cylinder, brands are forced to repaint cylinder to keep a good image. The shape of the cylinder though, is hard to repair.	The composite cylinders have, by far, a better design attention. The product look can keep the integrity for a longer time. In certain scenarios, the outer jacket can be changed on its design.
3 - (Acceptable)	**5 - (Very good)**

3.3.7.5 Strong product-user relation

When product design and performance match or exceed customer expectations, it is likely expected that customers will want to keep the product longer. This ownership will allow savings on environment, since there will be no need for replacement. Gas cylinders are less likely to create a relation with customer, also because most part of the times, they are owned by gas companies and rented to the user.

TABLE 47 - Strong product-user relation criteria evaluation

Steel Cylinder	Composite Cylinder
Design and ergonomics may help to be chosen but is not probable that will stay more time than necessary in customers' hands, due to the business model.	Design and ergonomics may help to be chosen but is not probable that will stay more time than necessary in customers' hands, due to the business model.
3 - (Acceptable)	**3 - (Acceptable)**

3.3.8 Optimization of end of life system

3.3.8.1 Re-use of product

The gas cylinders are submitted to a requalification after a certain period, that can change from market to market. Anyway, after the lifespan is finished it cannot be re-used, neither its material applied on a new cylinder, due to the changes on the mechanical properties. The re-use is being considered, for the gas products, the second life after the limits of requalification. After losing the required mechanical properties, the cylinder cannot be refurbished.

TABLE 48 - Re-use of product criteria evaluation

Steel Cylinder	Composite Cylinder
Not possible to give a second life to the same steel cylinder	Not possible to give a second life to the same composite cylinder
2 - (Bad)	**2 - (Bad)**

3.3.8.2 Remanufacturing/refurbishing

Despite the gas cylinders cannot have a second life, the remanufacturing or refurbishing can extend the lifespan of the products. The steel cylinders inspection and requalification period can vary accordingly to local regulation, as described on ANNEX II (United Nations, 2015). For composite: BS EN ISO 11623, Transportable gas cylinders, the periodic inspection and testing of composite gas cylinders can be seen in ANNEX III (The International Standards Organisation, 2013).

TABLE 49 - Remanufacturing/refurbishing criteria evaluation

Steel Cylinder	Composite Cylinder
Steel cylinders can be refurbished within a 15 years lifespan period.	Composite cylinders can be refurbished within a 10 years lifespan period.
5 - (Very good)	**4 - (Good)**

3.3.8.3 Recycling of materials

During the material selection, recyclable materials are preferred. After the lifespan of the product, if they can still be recyclable, the negative impact on the environment is limited. The materials found on both model's type in TABLE 13 and TABLE 14, are generally acceptable for recycling as summarized in TABLE 50. The paint solvent based used in the steel cylinders can be more difficult to manage, but its weight on total product, is very residual.

TABLE 50 - End-life materials to recycle, by model type (Gomes, 2013)

MATERIALS	STEEL CYLINDER	COMPOSITE CYLINDER
Steel	Recyclable	Recyclable
Zinc coat	Recyclable	
Paint (base solvent)	Non-recyclable	
Polymeric coat		Recyclable

High-density polyethylene	Recyclable
Composite	Recyclable

Composite cylinders have less presence of non-recyclable product, but the recycling process is more complex. From the separation of each part, to the time it requires, becomes the process more difficult.

TABLE 51 - Recycling of materials criteria evaluation

Steel Cylinder	Composite Cylinder
Almost all material from the steel cylinder, can be easily recycled and used in other products	All components need to be separated to be recycled accordingly. Most parts can be re-used in less exigent products.
5 - (Very good)	**3 - (Acceptable)**

3.3.8.4 Safer incineration

Some of the non-recyclable products used during the production and on the cylinders themselves, described in TABLE 13 and TABLE 14, are classified as dangerous goods and may require incineration. These items are summarized in TABLE 52:

TABLE 52 - Materials used in cylinder, for incineration (Gomes, 2013)

MATERIALS USED IN STEEL CYLINDERS PRODUCTION (DISPOSABLE)	FINAL DESTINY	MODEL
Hydraulic oil	Co-incineration	Composite/Steel
Solvent ink mud	Co-incineration	Steel only
Contaminated packages	Co-incineration	+ Steel / - Composite
Contaminated absorbers	Co-incineration	+ Steel / - Composite
Baths of revelation and fixation	Co-incineration	Steel only

Some products that would need incineration, are present in both models, but clearly, they are more prominent in the steel process.

TABLE 53 - Safer incineration criteria evaluation

Steel Cylinder	Composite Cylinder
Steel cylinders technology is more prone to use dangerous products, therefore, requiring a more impactable incineration.	Composite cylinders technology is using less dangerous products, therefore, less use of incineration.
2 - (Bad)	**3 - (Acceptable)**

3.4 LiDS Wheel model results

The evaluation of each criteria returned with the following summarized results in TABLE 54:

TABLE 54 - LiDS Wheel detailed evaluation

STRATEGIES/CRITERIA	STEEL CYLINDER	COMPOSITE CYLINDER
New concept development	2.75	3.25
- dematerialization	1	1
- shared use of product	4	4
- integration of functions	3	4
- functional optimization of product	3	4
Selection of low-impact materials	2.00	3.00
- cleaner materials	1	3
- renewable materials	1	1
- lower energy content materials	1	3
- recycled materials	5	4
- recyclable materials	5	4
Reduction of material usage	3.00	4.00
- reduction in weight	2	5
- reduction in volume	4	3
Optimization of production techniques	3.00	3.80
- alternative production techniques	3	4
- fewer production steps	3	3
- lower cleaner energy consumption	3	4
- less production waste	3	4
- fewer/cleaner production consumables	3	4
Optimization of distribution system	3.00	3.67
- less/cleaner/reusable packaging	4	4
- energy efficient transport mode	3	3
- energy efficient logistics	2	4
Reduction of impact during use	4.25	4.25
- lower energy consumption	5	5
- cleaner energy source	5	5
- cleaner consumables	4	4
- no waste of energy/consumables	3	3
Optimization of initial lifetime	3.20	3.60
- reliability and durability	4	3
- easier maintenance and repair	4	3
- modular product structure	2	4
- classic design	3	5
- strong product-user relation	3	3
Optimization of end of life system	3.50	3.00
- re-use of product	2	2
- remanufacturing/refurbishing	5	4
- recycling of materials	5	3
- safer incineration	2	3

To create the LiDS wheel, it was calculated the average of each strategy criteria, originating the following consolidated results in TABLE 55:

TABLE 55 - Results of the average evaluation of criteria on each strategy

STRATEGIES	STEEL CYLINDER	COMPOSITE CYLINDER
New concept development	2,75	3,25
Selection of low-impact materials	2,60	3,00

Reduction of material usage	3,00	4,00
Optimization of production techniques	3,00	3,80
Optimization of distribution system	3,00	3,67
Reduction of impact during use	4,25	4,25
Optimization of initial lifetime	3,20	3,60
Optimization of end of life system	3,50	3,00

The described assessment in TABLE 55 allows to build-up the following LiDS wheel on Figure 30

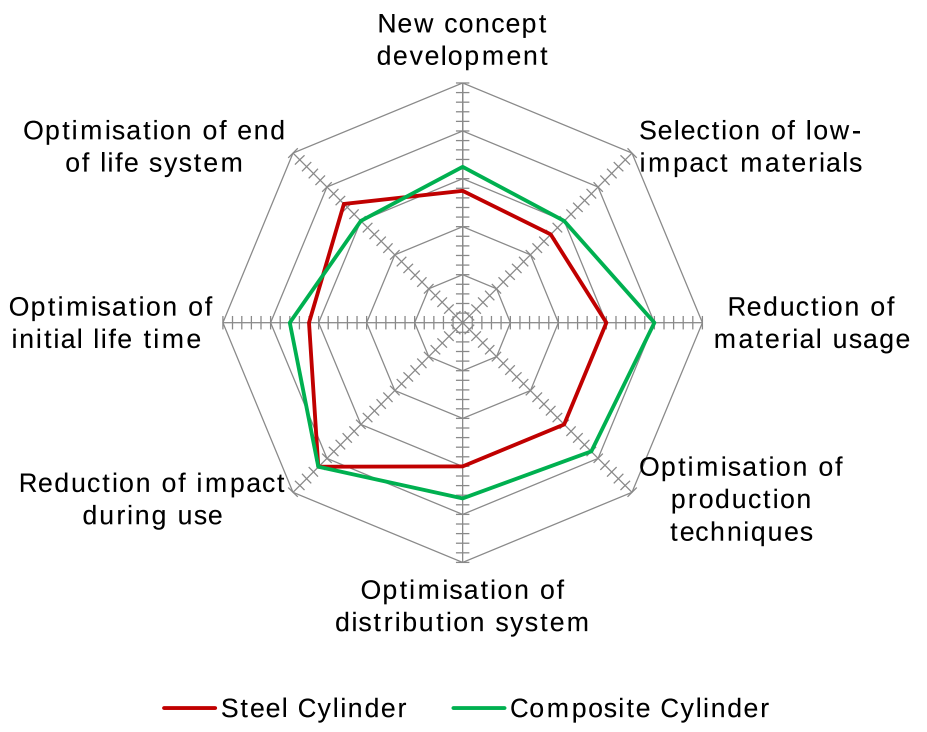

Figure 30 - LiDS wheel comparing Steel and Composite results

3.5 Results Interpretation

When looking at the LiDS wheel, the composite cylinder has clearly a bigger area, which means that has improved benefits (or fewer losses) to the environment when compared to the classic steel cylinders.

On the Optimization of end of life system strategy, the steel cylinders can be more effective, mostly driven by the extended life of the model when requalified, and the fact that all parts of the cylinder can be easily recycled.

The Reduction of material usage and Optimization of production techniques are favourable to the new composite cylinders' technology. The drastic weight reduction of the composite model, more than compensated the reduction of gas volume/content available. The techniques used on the new composite type, are more effective on reducing scrap, energy consumption and consumables.

The biggest gap though, where composite cylinders are more beneficial for the environment, refers to the selection of materials. Both cylinders use recyclable materials on its construction, but the materials used during the steel cylinder manufacture, such as oils, baths, welding scraps, solvent paint muds, etc, are extremely negative pushing the evaluation down on these criteria. With the LiDS wheel model implementation, is clear the additional benefits of using the new composite cylinders.

3.6 Results validation

Some studies were made on the environmental impact of different cylinders types, including the traditional steel and composite models.

To compare these materials and final product impact, it can be used many different methods as described before in this report. One of the methods is Environmental Priority Strategies (EPS).

The EPS approach is a systematic way to balance the design alternatives and process development. Basically, it defines the environmental impact costs, on each design and process alternatives, using the same way as the component's costs are calculated. Therefore, Environmental Priority Strategies (EPS) includes a quantification assessment, considering the classification and weighting, for the use of natural resources and process emissions. To quantify this damage cost impact, is used the Environmental Load Units (ELU) corresponding in such analysis to one Euro cost of environmental damage (Steen, 2015).

The Figure 31 is showing the difference of the environmental impact on different types of cylinders such as steel, aluminium, full composite and partial composite and steel cylinders, analysing the three relevant phases of lifecycle: the manufacturing part, the product use (considering a 30 years lifespan) and the released scrap. An Environmental Load Unit (ELU) quantification method was used for this comparison.

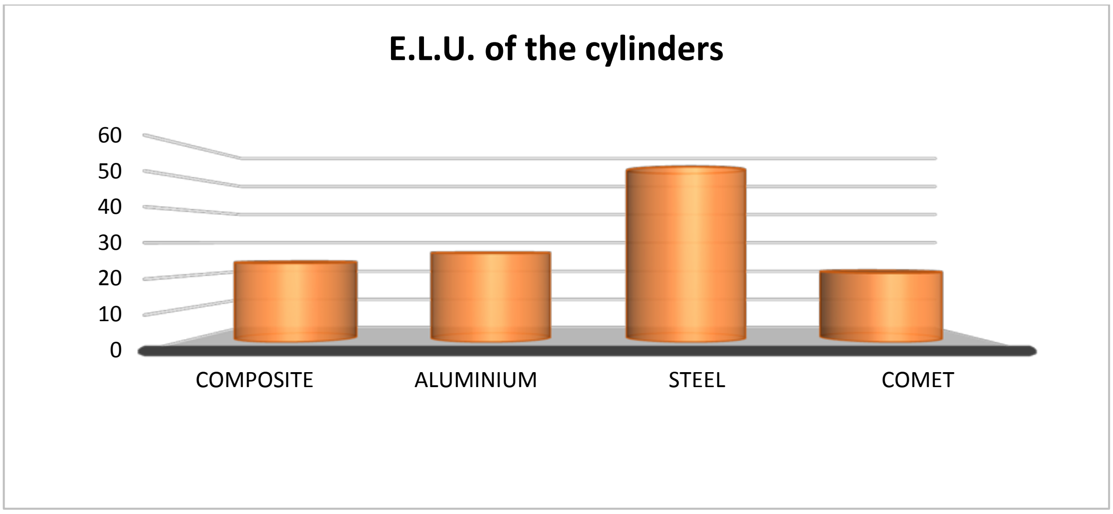

Figure 31 – ELU - Environmental Load Unit of different material cylinders (Vieira, 2010)

The first visual impact on this graph, is the steel high ELU cost relevancy. Despite the steel use is the most environmentally friendly when analysing the recyclability of the product, the positive point is not enough to mitigate the negative impact of the other phases, of manufacturing and use. On the manufacturing side, it uses a high-level of virgin product, high level of emissions during process and consumables difficult or impossible to recycle. On the product-use side, the extremely heavyweight, returns on high costs of carbon emissions during transports.

Aluminium cylinders and composite-only types are also interesting, but if aluminium has also a positive record on recycling, the cost, energy and time spent are higher when compared to steel. The composite-only type of cylinder is the lightest but requires thermoset use, which would be a negative factor on the recyclability record.

The composite and steel type (COMET) cylinder, is the model that better balance the impact on the three stages, when compared with all the types but proving this way too, that its impact to the environment has a less negative impact than the steel type. The arguments used in this study, are consistent with the ones made along the LiDS wheel evaluation.

CONCLUSIONS

4.1 MAIN CONCLUSIONS
4.2 PERSONAL OUTCOMES
4.3 SUGGESTIONS FOR FUTURE RESEARCHES

4 CONCLUSIONS

4.1 Main conclusions

The goals presented at the beginning of this project were accomplished, indagating through the literature, the support to collect and analyse relevant information about these two cylinders types, steel and composite. Based on the Lids Wheel results, it was possible to obtain relevant information about the lifecycle of both models, not only enhancing the aspects where each one of the models can be clearly distinguished, but also where both products can be improved.

The processes used, were also part of the analysis. The steel cylinder requires the use of more harmful consumables while composite technology requires more electric energy. The fact that composite technology is using innovative materials and technologies during production, turns the final process more energy efficient, with less environmental impacts.

The product storage was not so benefited with the switch from the steel cylinders to composites, but the benefits from the emission reduction during transport were enormous for the composite cylinder. A substantial weight reduction reduced the cost of the product ownership, for the gas companies and the environmental cost for society.

The final stage of the product is mostly driven by the material selection and the impact of the involved processes. Both models proved to be recyclable through their materials characteristics, becoming more consumer-friendly, not requiring the use of more harmful materials.

The Environmental Load Unit (ELU) analysis, was not detailed enough to cross-check the impact of each one of the criteria described in the LiDS Wheel but allowed to confirm the final result, reinforcing the conclusions achieved by this Eco-design tool.

The composite cylinder technology tried to satisfy customer's demand by reducing weight and give an appellative design to a traditional and industrial-looking cylinder. This new technology achieved those goals by using different types of materials but selecting the ones with less impact for the environment, before, during and after the product manufacture. This innovation resulted in a tremendous success, with great acceptance from consumers.

The implementation of an Eco-design tool as LiDS to assess the analysis of both products, allowed to prove, with a reliable tool, that it is possible to improve or create new products, and reduce negative impacts on the environment at the same time.

The TABLE 56 summarizes the achievements brought by the use of the new composite + steel technology when compared with the traditional steel-only kind of LPG cylinders.

TABLE 56 - Improvements achieved

IMPROVEMENTS ACHIEVED BY SWITCHING FROM TRADITIONAL STEEL CYLINDERS TO COMPOSITE	
Improved and appealing design	√
Consumer-friendly - lighter, ergonomic	√
Use of lower environmental impact materials	√
More energy efficient processes	√
Reduction of CO_2 emission s during transport	√
Recyclable product	√

4.2 Personal outcomes

With the results obtained from this report, there are thoughts to collect from different areas. The importance of the environmental impact on product development is clear, not only from the citizenship importance and the increasing recognition from the consumers' side, but also because regulation is becoming stricter on product evaluation through all its life-cycle. The better companies can anticipate and prepare for these changes, the better they will succeed. The growing ecological mindset from the industry, driven by consumers expectations and the United Nations path, requires new methods and tools improvement, so metrics can be permanently measured by assessing better decisions and reactions.

The gas cylinder industry is extremely regulated but recent innovations proved that even in such market reality, there is space for improvement and innovation. The use of composite is quite recent when compared with the steel technology. With the new technologies growing exponentially, new and improved materials are expected to appear. The companies with the audacity of switching from the comfortable use of their equipment, to uncertain directions, will be able to be the firsts to collect the fruit of their courage, with consumer recognition and obtaining the premium prices advantages.

The advantage of the composite materials use, when compared with the steel cylinders, is not a strict and definitive conclusion. Along with the analyses made, steel was a better option in many aspects. The process of working the steel, was the main topic that compromised the used of this material, and not the material itself. To focus on processes efficiency and cleaner options, is so important as the material selection. The quantification of the impacts, through a global and common classification such as the Environmental Load Units (ELU) for example, can help product developers to anticipate the better routes for the materials and processes, running from the old classic materials' cost only philosophy.

4.3 Suggestions for future researches

The next step for similar works within the sector of gas cylinders, would be a deep Life Cycle Assessment to the composite type of cylinders, considering that the introduction of this product was about 15 years ago. Therefore, refurbishing and requalification are starting their process, allowing to get a better picture of the product life extension, materials performance, costs and material recycling effective success.

BIBLIOGRAPHY AND OTHER SOURCES

5 BIBLIOGRAPHY AND OTHER RESOURCES

Agudelo, L., Mejía-gutiérrez, R., Nadeau, J., Agudelo, L., Mejía-gutiérrez, R., Nadeau, J. and Pailhes, J. (2017) 'Life cycle analysis in preliminary design stages', *Joint Conference on Mechanical Design Engineering and Advanced Manufacturing*, pp. 1–7. doi: hal-01066385isbn:hal-01066385.

de Aguiar, J., de Oliveira, L., da Silva, J. O., Bond, D., Scalice, R. K. and Becker, D. (2017) 'A design tool to diagnose product recyclability during product design phase', *Journal of Cleaner Production*. Elsevier Ltd, 141, pp. 219–229. doi: 10.1016/j.jclepro.2016.09.074isbn:09596526.

AMTROL-ALFA (2018) *Comet Cylinders range - Catalogue*, *AMTROL-ALFA website*. Available at: http://amtrol-alfa.com/wp-content/files_mf/1479120462161110_AMTROLCOMETint.pdf.

Andriankaja, H., Vallet, F., Le Duigou, J. and Eynard, B. (2015) 'A method to ecodesign structural parts in the transport sector based on product life cycle management', *Journal of Cleaner Production*. Elsevier Ltd, 94, pp. 165–176. doi: 10.1016/j.jclepro.2015.02.026.

Asia Industrial Gases Association (2014) 'A reference guides for requalification of gas cylinders', *AIGA*, 090/14

Asmatulu, E., Twomey, J. and Overcash, M. (2014) 'Recycling of fiber-reinforced composites and direct structural composite recycling concept', *Journal of Composite Materials*, 48(5), pp. 593–608. doi: 10.1177/0021998313476325isbn:9780000000002.

Bal, M., Bryde, D., Fearon, D. and Ochieng, E. (2013) 'Stakeholder Engagement: Achieving Sustainability in the Construction Sector', *Sustainability*, 5(2), pp. 695–710. doi: 10.3390/su5020695isbn:2071-1050.

Basiago, A. D. (1999) *Economic, Social, and Environmental Sustainability in Development Theory and Urban Planning Practice*, *The Environmentalist*. Boston: Kluwer Academic Publishers. doi: 10.1023/A:1006697118620isbn:0251-1088.

Behrisch, J., Ramirez, M. and Giurco, D. (2011) 'Representation of Ecodesign Practice: International Comparison of Industrial Design Consultancies', *Sustainability*, 3(10), pp. 1778–1791. doi: 10.3390/su3101778isbn:978-1-904670-25-4.

Biois (2013) 'Material-efficiency Ecodesign Report and Module to the Methodology for the Ecodesign of Energy-related Products (MEErP)', *European Commission - DG Enterprise and Industry 5*, (July)

Boks, C. (2006) 'The soft side of ecodesign', *Journal of Cleaner Production*, 14(15–16), pp. 1346–1356. doi: 10.1016/j.jclepro.2005.11.015isbn:0959-6526.

Bonou, A., Skelton, K. and Olsen, S. I. (2016) 'Ecodesign framework for developing wind turbines', *Journal of Cleaner Production*. Elsevier Ltd, 126, pp. 643–653. doi: 10.1016/j.jclepro.2016.02.093isbn:0959-6526.

Bras, B. (1997) ‘Incorporating Environmental Issues in Product Design and Realization’, *Industry And Environment*, 20(1), pp. 1–19. doi: 10isbn:0378-9993.

Bressmann, T. (2004) ‘Self-inflicted cosmetic tongue split: a case report.’, *Journal (Canadian Dental Association)*, 70(3), pp. 156–7. doi: 10.1088/1751-8113/44/8/085201isbn:9780874216561.

Brones, F. A., Carvalho, M. M. de and Zancul, E. de S. (2017) ‘Reviews, action and learning on change management for ecodesign transition’, *Journal of Cleaner Production*. Elsevier Ltd, 142, pp. 8–22. doi: 10.1016/j.jclepro.2016.09.009isbn:0959-6526.

Buchert, T., Halstenberg, F. A., Bonvoisin, J., Lindow, K. and Stark, R. (2017) ‘Target-driven selection and scheduling of methods for sustainable product development’, *Journal of Cleaner Production*. Elsevier B.V., 161, pp. 403–421. doi: 10.1016/j.jclepro.2017.05.067.

Bundgaard, A. M., Mosgaard, M. A. and Remmen, A. (2017) ‘From energy efficiency towards resource efficiency within the Ecodesign Directive’, *Journal of Cleaner Production*. Elsevier B.V., 144, pp. 358–374. doi: 10.1016/j.jclepro.2016.12.144isbn:09596526.

Bundgaard, A. M., Remmen, A. and Zacho, K. O. (2015) ‘Ecodesign Directive version 2.0’, *From Energy Efficiency to Resource Efficiency*, (1635), pp. 1–108. isbn:978-87-93283-56-5.

Chistilin, D. (2010) ‘Sustainable Economic Development: The Main Principles and the Basic Equation’, in *Romanian Journal of Economics*, pp. 95–109. Available at: https://ideas.repec.org/a/ine/journl/v1y2010i39p95-109.html.

Choi, J.-K., Stuart, J. A., Ramani, K. and Sciences, I. S. for E. I. (2003) ‘Decision Support Tools for Environmental Product and Process Management: Survey and Needs’, *ISEIS - International Society for Environmental Information Sciences Decision*, 1(January), pp. 24–37. Available at: https://engineering.purdue.edu/PRECISE/Publications/DecisionSupportToolsforEnvironmentalProductandProce/Conf%232_Choi.pdf.

Composites World (2018) *Pressure vessel tank types*, *Composites World*. Available at: https://www.compositesworld.com/articles/pressure-vessel-tank-types.

Conformance UK (2018) *Transportable Pressure Equipment*. Available at: https://www.conformance.co.uk/ce-marking/68-ce-directives/general/220-transportable-pressure-equipment#administration-requirements.

Dai, Q., Kelly, J., Sullivan, J. and Elgowainy, A. (2015) ‘Life-Cycle Analysis Update of Glass and Glass Fiber for the GREET Model’, *Argonne National Laboratory*, (September), p. 25. Available at: https://greet.es.anl.gov/files/glass-fiber-update.

Dalhammar, C. (2016) ‘Industry attitudes towards ecodesign standards for improved resource efficiency’, *Journal of Cleaner Production*. Elsevier Ltd, 123, pp. 155–166. doi: 10.1016/j.jclepro.2015.12.035isbn:0959-6526.

ECE Global, L. (2018) *CE & Pi Marking*, *Effective Compliance Engineering in Technology and Systems*. Available at: http://www.eceglobal.com/services/pre-certification-consulting/ce-pi-marking/.

ECTA (2011) ‘Guidelines for Measuring and Managing CO 2 Emission from Freight Transport Operations’, *Ecta Rc*, march(1), p. 19. Available at: https://www.ecta.com/resources/Documents/Best Practices Guidelines/guideline_for_measuring_and_managing_co2.pdf.

European Commission (2012) ‘Ecodesign’, *Ecodesign Your Future*, p. 12

European Parliament and Council (2010) 'Directive 2010/35/EU on transportable pressure equipment TPED', *Official Journal Of The European Union*, L 165/1(May). Available at: http://www.conformance.co.uk/adirectives/doku.php?id=transportpressure.

Ferrendier, D. S., Mathieux, F., Rebitzer, G., Simon, D. M. and Froelich, P. D. (2002) 'Eco-design guide - Environmentally improved product design Case studies of the european electrical and electronics industry', *ECOLIFE Network*. Edited by P. D. FROELICH, D. V. HERMAN, D. B. KOPACEK, and M. BRANDSTÖTTER, (July)

Fijał, T. (2007) *An environmental assessment method for cleaner production technologies*, *Journal of Cleaner Production*. doi: 10.1016/j.jclepro.2005.11.019.

General Assembly of the United Nations (2018) *Sustainable Development*. Available at: http://www.un.org/en/ga/president/65/issues/sustdev.shtml.

Giovannoni, E. and Fabietti, G. (2013) *Integrated Reporting*, *What Is Sustainability? A Review of the Concept and Its Applications*. Edited by C. Busco, M. L. Frigo, A. Riccaboni, and P. Quattrone. Cham: Springer International Publishing. doi: 10.1007/978-3-319-02168-3isbn:978-3-319-02167-6.

Gomes, D. P. (2013) *Sistema Integrado de Gestão QAS*, *Instituto Politécnico do Cávado*. Instituto Politécnico do Cávado

Goosen, M. F. A. (2012) 'Environmental management and sustainable development', *Procedia Engineering*, 33(December 2012), pp. 6–13. doi: 10.1016/j.proeng.2012.01.1171isbn:1877-7058.

Grant, D., Trautrims, A. and Wong, C. (2015) *Sustainable Logistics and Supply Chain Management (Revised Edition)*. Edited by Kogan Page. Kogan Page. isbn:9780749468675.

Hasanbeigi, A., Price, L. and Aden, N. (2011) 'A Comparison of Iron and Steel Production Energy Use and Energy Intensity in China and the U.S.', *Ernest Orlando Lawrence Berkeley National Laboratory*, (June), p. 87. Available at: https://eaei.lbl.gov/sites/all/files/lbl-4836e-us-china-steeljune-2011.pdf%0Ahttps://china.lbl.gov/sites/all/files/lbl-4836e-us-china-steeljune-2011.pdf.

den Hollander, M. C., Bakker, C. A. and Hultink, E. J. (2017) 'Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms', *Journal of Industrial Ecology*, 21(3), pp. 517–525. doi: 10.1111/jiec.12610isbn:1088-1980.

Van Holsteijn en Kemna (VHK) (2015) 'Ecodesign Impact Accounting. Final – Status May 2015. Report for the European Commission', *Report for the European Commission*, (May)

International Standard Organization (2006) *ISO 14040 Environmental management — Life cycle assessment — Principles and framework*. ISO copyri, *Environmental management — Life cycle assessment — Principles and framework Management*. ISO copyri. Edited by ISO copyright office Case. Geneva: ISO copyright office Case. Available at: https://www.iso.org/obp/ui/#iso:std:iso:14040:ed-2:v1:en.

Jayatilaka, P. R., Kulatunga, A. K. and Ekanayake, E. A. R. S. (2016) 'Incorporating Sustainable Concepts for Product Design, Development and Manufacturing', (May), pp. 1–14. Available at: https://www.researchgate.net/publication/301787966%0AINCORPORATING.

Jeronen, E. (2013) 'Sustainability and Sustainable Development', in *Encyclopedia of Corporate Social Responsibility*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 2370–

2378. doi: 10.1007/978-3-642-28036-8_662isbn:3642280358.

Khalili, N. R., Duecker, S., Ashton, W. and Chavez, F. (2015) ‘From cleaner production to sustainable development: the role of academia’, *Journal of Cleaner Production*. Elsevier Ltd, 96, pp. 30–43. doi: 10.1016/j.jclepro.2014.01.099isbn:0959-6526.

Khasreen, M. M., Banfill, P. F. G. and Menzies, G. F. (2009) ‘Life-cycle assessment and the environmental impact of buildings: A review’, *Sustainability*, 1(3), pp. 674–701. doi: 10.3390/su1030674isbn:2071-1050.

Kikuchi, Y. (2016) ‘Life Cycle Assessment’, in *Plant Factory*. Elsevier, pp. 321–329. doi: 10.1016/B978-0-12-801775-3.00024-X.

Knight, P. and Jenkins, J. O. (2009) ‘Adopting and applying eco-design techniques: a practitioners perspective’, *Journal of Cleaner Production*. Elsevier Ltd, 17(5), pp. 549–558. doi: 10.1016/j.jclepro.2008.10.002isbn:0959-6526.

Koroneos, C. J. and Rokos, D. (2012) ‘Sustainable and Integrated Development—A Critical Analysis’, *Sustainability*, 4(1), pp. 141–153. doi: 10.3390/su4010141isbn:2071-1050.

Lee, J. J. (2011) ‘NHS reform. Study proposal.’, *BMJ (Clinical research ed.)*. Elsevier Ltd, 342(8), p. d2584. doi: 10.1088/1751-8113/44/8/085201isbn:0016-7185.

Lee, K.-M. and Inaba, A. (2004) ‘Life Cycle Assessment Best Practices of ISO 14040 Series’, *Comittee in Trade and Investment*. Center for Ecodesign and LCA (CEL), Ajou University, (February), p. 96. isbn:981-05-0590-6.

Lofthouse, V. (2006) ‘Ecodesign tools for designers: defining the requirements’, *Journal of Cleaner Production*, 14(15–16), pp. 1386–1395. doi: 10.1016/j.jclepro.2005.11.013isbn:0959-6526.

Magerholm, F. A. (2014) ‘Environmental Management Tools and Their Application – a Review With References To Case Studies’, (October), pp. 1–14. Available at: https://www.researchgate.net/publication/242325558%0AENVIRONMENTAL.

Maio, F. Di, Lotfi, S., Bakker, M., Hu, M. and Vahidi, A. (2017) ‘Advances in recycling and management of construction’, in Maio, F. Di, Lotfi, S., Bakker, M., Hu, M., and Vahidi, A. (eds) *HISER International Conference Advances*. Antwerp, Belgium, p. 96. isbn:978-94-6186-826-8.

Marques, B., Tadeu, A., De Brito, J. and Almeida, J. (2017) ‘A Perspective on the Development of Sustainable Construction Products: An Eco-Design Approach’, *International Journal of Sustainable Development and Planning*, 12(02), pp. 304–314. doi: 10.2495/SDP-V12-N2-304-314.

Martin Charter, Scott Keiller, V. C. (2018) ‘Eco-design for the construction industry’, *The Centre for Sustainable Design*, p. 48

Masoudi, A., You, H.-C. and Suh, S.-H. (2012) ‘Characterization of Eco-Design Checklists’, *Journal of the Korean Society of Precision Engineering*, 29(9), pp. 964–970. doi: 10.7736/KSPE.2012.29.9.964.

Matthews, W. G. and Zeissig, D. H. R. (2011) ‘Residential Market for LPG: A Review of Experience of 20 Developing Countries’, *HOUSTON INTERNATIONAL BUSINESS CORP. Energy and Environmental Policy Consultants*, (December), p. 196. Available at: http://siteresources.worldbank.org/INTOGMC/Resources/Review_of_LPG_market_in_20_countries_2011.pdf.

Midžić, I., Štorga, M. and Marjanović, D. (2015) ‘Eco-Evaluation in Conceptual Design Phase – a

Case Study', *TRANSACTIONS OF FAMENA XXXIX*, 3, pp. 47–60

Mieras, E. (2018) *Putting the metrics behind sustainability*, *Pre-Sustainability*. Available at: https://www.pre-sustainability.com/sustainability-consulting/sustainable-practices/custom-sustainability-software.

Milojevic, I. and Simic, D. (2008) 'Anesthesia in pyruvate dehydrogenase deficiency.', *Paediatric anaesthesia*, 18(8), pp. 794–5. doi: 10.1111/j.1460-9592.2008.02545.xisbn:978-3-319-14001-8.

Munn, R. E. (1992) 'Towards sustainable development', *Atmospheric Environment. Part A. General Topics*, 26(15), pp. 2725–2731. doi: 10.1016/0960-1686(92)90007-8isbn:978-91-7264-416-8.

Muñoz-Torres, M. J., Fernández-Izquierdo, M. ángeles, Rivera-Lirio, J. M., Ferrero-Ferrero, I., Escrig-Olmedo, E., Gisbert-Navarro, J. V. and Marullo, M. C. (2018) 'An Assessment Tool to Integrate Sustainability Principles into the Global Supply Chain', *Sustainability*, 10(3), p. 535. doi: 10.3390/su10020535.

Navajas, A., Uriarte, L. and Gandía, L. M. (2017) 'Application of Eco-Design and Life Cycle Assessment Standards for Environmental Impact Reduction of an Industrial Product', *Sustainability*. Navarra, 9(10), p. 1724. doi: 10.3390/su9101724isbn:2071-1050.

Nilsen, K. (2011) *Development of Low Pressure filter testing vessel and analysis*. Wichita State University in. Available at: https://soar.wichita.edu/bitstream/handle/10057/3997/t11029_Nilsen.pdf?sequence=3.

Ogbonna, H. (2018) *Sustainable Development goals*, *Presentation*. Available at: https://slideplayer.com/slide/10630529/.

Patay, C. (2009) *The use of recycled and renewable materials The use of recycled and renewable materials*. KTH Industrial Engineering and Management. doi: MMK 2009:82 MCE 211.

Paula Pinheiro, M. A., Jugend, D., Demattê Filho, L. C. and Armellini, F. (2018) 'Framework proposal for ecodesign integration on product portfolio management', *Journal of Cleaner Production*, 185, pp. 176–186. doi: 10.1016/j.jclepro.2018.03.005.

Pernot, C., Hoeffel, J. C., Henry, M. and Piwnica, A. (1978) 'Case report of congenital tricuspid insufficiency.', *Catheterization and cardiovascular diagnosis*, 4(1), pp. 71–9. isbn:02-03.

Pigosso, D. C. a, Mcaloone, T. C. and Rozenfeld, H. (2014) 'Systematization of Best Practices for Ecodesign Implementation', *Proceedings of the 13th International Design Conference DESIGN 2014*, (1), pp. 1651–1662. Available at: https://www.designsociety.org/download-publication/35308/systematization_of_best_practices_for_ecodesign_implementation.

Plouffe, S., Lanoie, P., Berneman, C. and Vernier, M.-F. (2011) 'Economic benefits tied to ecodesign', *Journal of Cleaner Production*, 19(6–7), pp. 573–579. doi: 10.1016/j.jclepro.2010.12.003isbn:09596526.

Porrini, D. and Striani, F. (2017) 'Sustainable Development as a Macro-Regional Goal', *Journal of Reviews on Global Economics*, 6, pp. 87–97. doi: 10.6000/1929-7092.2017.06.07.

Pradhan, P., Costa, L., Rybski, D., Lucht, W. and Kropp, J. P. (2017) 'A Systematic Study of Sustainable Development Goal (SDG) Interactions', *Earth's Future*, 5(11), pp. 1169–1179. doi: 10.1002/2017EF000632.

Resolution, C. and Council, T. H. E. (1985) ‘Council Resolution of 7 May 1985 on a new approach to technical harmonization and standards’, *Official Journal of the European Communities*, 85/C 136/0(C), pp. 1–9

Rio, M., Reyes, T. and Roucoules, L. (2011) ‘A framework for Ecodesign: an interface between LCA and design process’, *ANNALS OF FACULTY ENGINEERING HUNEDOARA – International Journal Of Engineering*, Fascicule, pp. 121–126

Rossi, M., Germani, M. and Zamagni, A. (2016) ‘Review of ecodesign methods and tools. Barriers and strategies for an effective implementation in industrial companies’, *Journal of Cleaner Production*. Elsevier Ltd, 129, pp. 361–373. doi: 10.1016/j.jclepro.2016.04.051.

Rousseaux, P., Gremy-Gros, C., Bonnin, M., Henriel-Ricordel, C., Bernard, P., Floury, L., Staigre, G. and Vincent, P. (2017) ‘“Eco-tool-seeker”: A new and unique business guide for choosing ecodesign tools’, *Journal of Cleaner Production*, 151, pp. 546–577. doi: 10.1016/j.jclepro.2017.03.089isbn:09596526 (ISSN).

Sakr, D. and Abo Sena, A. (2017) ‘Cleaner production status in the Middle East and North Africa region with special focus on Egypt’, *Journal of Cleaner Production*. Elsevier Ltd, 141, pp. 1074–1086. doi: 10.1016/j.jclepro.2016.09.160isbn:0959-6526.

Schöggl, J.-P., Baumgartner, R. J. and Hofer, D. (2017) ‘Improving sustainability performance in early phases of product design: A checklist for sustainable product development tested in the automotive industry’, *Journal of Cleaner Production*. Elsevier Ltd, 140, pp. 1602–1617. doi: 10.1016/j.jclepro.2016.09.195isbn:0959-6526.

Solidworks (2018) *Conceptual Life Cycle Thinking*, *Solidworks website*. Available at: http://www.solidworks.com/sustainability/sustainable-design-guide/ch4-conceptual-life-cycle-thinking.htm.

Steen, B. (2015) *The EPS 2015d impact assessment method – an overview*. Göteborg, Sverige. Available at: https://www.ivl.se/download/18.7e136029152c7d48c202bc2/1465979613730/The EPS 2015 impact assessment method_An overview_SLC Report 2015_5.pdf.

Stellwagen, E. and Babul, J. (1975) ‘Stabilization of the globular structure of ferricytochrome c by chloride in acidic solvents.’, *Biochemistry*, 14(23), pp. 5135–40. doi: 10.1088/1751-8113/44/8/085201isbn:019282080X.

Sugawara, E. and Nikaido, H. (2014) ‘Properties of AdeABC and AdeIJK Efflux Systems of Acinetobacter baumannii Compared with Those of the AcrAB-TolC System of Escherichia coli’, *Antimicrobial Agents and Chemotherapy*, 58(12), pp. 7250–7257. doi: 10.1128/AAC.03728-14isbn:0264-2751.

Sustainable Development Solutions Network (2016) ‘Practical tools for getting started with the SDGs’, in *Getting Started with the SDGs in Cities: A Guide for Stakeholders*, p. 121. Available at: http://unsdsn.org/wp-content/uploads/2016/07/9.1.8.-Cities-SDG-Guide.pdf.

Tao, J., Li, L. and Yu, S. (2018) ‘An innovative eco-design approach based on integration of LCA, CAD\CAE and optimization tools, and its implementation perspectives’, *Journal of Cleaner Production*, 187, pp. 839–851. doi: 10.1016/j.jclepro.2018.03.213.

Taylor, B. (2006) ‘Encouraging industry to assess and implement cleaner production measures’, *Journal of Cleaner Production*, 14(6–7), pp. 601–609. doi: 10.1016/j.jclepro.2005.07.013isbn:09596526.

The Compressed Gas Association (2013) 'Celebrating 100 Years as The Standard for Safety : The Compressed Gas Association, Inc. 1913 – 2013', *Compressed Gas Association Magazine*

The International Standards Organisation (2004) 'ISO 14001 - Environmental Management Systems— Requirements with Guidance for Use', *ISO-International Organisation for Standardization*, 2004(2), pp. 1–32. Available at: https://www.iso.org/files/live/sites/isoorg/files/archive/pdf/en/introduction_to_iso_14001.pdf.

The International Standards Organisation (2011) *ISO 14006 - Environmental management systems — Guidelines for incorporating ecodesign*, *ISO-International Organisation for Standardization*. doi: 10.5594/J09750isbn:2831889189.

The International Standards Organisation (2013) 'ISO 11623 - Transportable gas cylinders - Periodic inspection and testing of composite gas cylinders', *The International Standards Organisation*, 552. doi: 10.1520/G0154-12Aisbn:0784406243.

The International Standards Organisation (ISO 14044) (2006) 'ISO 14044 Environmental management — Life cycle assessment — Requirements and guidelines', *The International Journal of Life Cycle Assessment*, 2006(7), pp. 652–668. doi: 10.1007/s11367-011-0297-3isbn:5935522004.

Tsiamis, D. and Castaldi, M. (2016) 'Determining accurate heating values of non-recycled plastics (NRP)', *City University of New York*, p. 11. Available at: https://plastics.americanchemistry.com/Energy-Values-Non-Recycled-Plastics.pdf.

TÜV SÜD AG (2014) 'Transportable pressure equipment', *TUV SUD*. Available at: www.tuv-sud.com/steamandpressure.

U.S. Environmental Protection Agency (2007) 'Energy Trends in Selected Manufacturing Sectors', *U.S. Environmental Protection Agency*, (March), p. 4

United Nations (2015) *European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR 2015)*. Economic Commission for Europe Committee on Inland Transport. isbn:9789211391312.

United Nations (2018) *Goal 12: Ensure sustainable consumption and production patterns*, *Sustainable Development Goals*. Available at: https://www.un.org/sustainabledevelopment/sustainable-consumption-production/.

United Nations Developing Program (UNEPD) (2018) *Goal 12 - Targets*, *Goal 12 - Targets*. Available at: http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-12-responsible-consumption-and-production/targets.html.

United Nations Environment Programme (2012) 'Greening the economy through life cycle thinking', *United Nations Environment Programme*. Ten Years, p. 59. isbn:9789280732689.

University of Wollongong (2012) 'Storage and Handling of Gas Cylinders', HRD-WHS-GU, pp. 1–15

Vella, K. (2016) 'The Environmental Dimension of the 2030 Agenda', *Go Circular*. Edited by G. Lean. Nairobi, Kenia: United Nations Environment Programme The, (Our Planet), p. 36. Available at: www.unep.org/ourplanet.

Vicente, J., Frazão, R. and Moreira da Silva, F. (2011) 'Ecodesign Tools: One basis to operationalize Sustainable Design', *CIPED - VI International Congress on Design Research, Lisbon, Portugal*, (4), pp. 3–6

Vieira, C., Alves, J. and Roque, M. (2013) ‘Manual Prático de Ecodesign’, *AEP - Manual Prático de Ecodesign*. Edited by AEP- Associação Empresarial de Portugal. AEP- Associação Empresarial de Portugal, p. 108. isbn:978-972-8702-83-0.

Vieira, L. C. and Amaral, F. G. (2016) ‘Barriers and strategies applying Cleaner Production: a systematic review’, *Journal of Cleaner Production*. Elsevier Ltd, 113, pp. 5–16. doi: 10.1016/j.jclepro.2015.11.034isbn:09596526.

Vieira, P., Tenreiro, A. and Oliveira, T. (2010) ‘The increase of sustainability in cylinder manufacturing’, *Clean Technologies and Environmental Policy*, 12(1), pp. 83–86. doi: 10.1007/s10098-009-0224-5.

Vila, C., Abellán-Nebot, J. V., Albiñana, J. C. and Hernández, G. (2015) ‘An Approach to Sustainable Product Lifecycle Management (Green PLM)’, *Procedia Engineering*. Elsevier B.V., 132(February 2016), pp. 585–592. doi: 10.1016/j.proeng.2015.12.608.

Vitali, I., Arquilla, V. and Tolino, U. (2017) ‘A Design perspective for IoT products. A case study of the Design of a Smart Product and a Smart Company following a crowdfunding campaign’, *The Design Journal*. Routledge, 20(sup1), pp. S2592–S2604. doi: 10.1080/14606925.2017.1352770.

Wallhagen, M. (2016) *Environmental Assessment Tools for Neighbourhoods and Buildings in relation to Environment , Architecture , and Architects (Comprehensive summary)*. isbn:9789177291237.

Weinberger, K., Rankine, H., Amanuma, N., Surendra, L. and Hull, H. V. V. (2015) ‘Integrating the three dimensions of sustainable development A framework and tools’, in *Greening of Economic Growth Series*. Katinka Weinberger, Hitomi Rankine, Nobue Amanuma, Lawrence Surendra and Heather Victoria Van Hull. Available at: https://www.unescap.org/sites/default/files/Integrating the three dimensions of sustainable development A framework.pdf.

Wever, R. and Vogtlander, J. (2017) *Handbook of Ethics, Values, and Technological Design*, *Handbook of Ethics, Values, and Technological Design*. Edited by J. van den Hoven, P. E. Vermaas, and I. van de Poel. Dordrecht: Springer Netherlands. doi: 10.1007/978-94-007-6994-6isbn:978-94-007-6994-6.

Wever, R. and Vogtländer, J. (2014) ‘Design for the Value of Sustainability’, in *Handbook of Ethics, Values, and Technological Design*. Dordrecht: Springer Netherlands, pp. 1–31. doi: 10.1007/978-94-007-6994-6_20-1isbn:978-94-007-6994-6.

Wiche, P. and Vladivia, S. (2014) ‘Life Cycle Thinking in Latin America 12 case studies of LCA and LCM approaches of companies in the region’, *Life Cycle Thinking in Latin America*, p. 16. Available at: https://www.lifecycleinitiative.org/wp-content/uploads/2015/01/LCA-LCM-company-case-studies-in-Latin-America.pdf.

WRAP (2013) ‘Your Guide to Environmental Management Systems waste’, p. 64. Available at: http://www.wrap.org.uk/content/your-guide-environmental-management-systems-ems.

Zampori, L., Saouter, E., Schau, E., Cristobal, J., Castellani, V. and Sala, S. (2016) ‘Guide for interpreting life cycle assessment result’, *Publications Office of the European Union*, p. 60. doi: 10.2788/171315isbn:979-92-79-64114-5.

ANNEXES

6.1 ANNEX I
6.2 ANNEX II
6.3 ANNEX III
6.4 ANNEX IV

6 ANNEXES

6.1 ANNEX I

10 Guidelines for Ecodesign	Environmental Product Life Cycle Matrix (EPLC)
ABC Analysis	Environmental Value Chain Analysis (EVCA)
Alternative Function Fulfillment (AFF)	Environmentally Conscious QFD (ECQFD)
ATROiD EcoDesign Tool	Environmentally conscious quality function
BOM Check	ENVRIZ
Business Process Reengineering (BPR)	Factor X Tool 2001
C2P (Compliance to Products)	euroMat
Checklist-Based Assessment Support System for Ecodesign (CHASSE)	Environmentally responsible product/product assessment matrix (ERP)
Corporate Integration of Voluntary Initiatives for Sustainability (CIVIS)	Readiness Assessment for Implementing DfE Strategies (RAILS)
D4N	grEEEn Technique
Design Abacus	Green Design Advisor (GDA)
Design for Recycling Methodology	Green QFD
DfE Matrix	House of Ecology, HoE
Eco Communication Matrix	Information/Inspiration web-based tool
EcoBenchmarking	Instep-DfE
ECODESIGN Checklist method (ECM)	LiDs Wheel
Eco-design Matrix	SimaPro
Ecodesign Online	Life Cycle Check (LCC)
EcoDesign Pilot	Life Cycle Quality Function Deployment (LC-QFD)
Ecoquest	Life Cycle Scenario Description Support Tool
Ecodesign Technique for Electronics Products	LIME technique
Ecodesign Web	Matrix Element Checklist
ECOFAIRE	MATto Material Library
Eco-Function Matrix	MECO Matrix
Eco-indicator 99	MET Matrix
Eco-indicator tool (Eco-it)	Packaging Impact Quick Evaluation Tool (PIQET)
Eco-Innovative Tool	Philips Fast Five Awareness
Eco-material evaluation diagram	Product Improvement Matrix
Econcept Spiderweb	Product Life Cycle Planning (LCP)
Eco-QFD (Ecological QFD)	Quality Function Deployment for Env (QFDE)
Eco-Re-design	Recyclability evaluation technique
Eco-roadmap	Remanufacturing Guideline
EcoValue	Ten Golden Rules
EIAtrack	Total REACH Score
EIME software	Upgrade Cycle Explorer
Environmental Effect Analysis (EEA)	GaBi
Environmental impact and factor analysis	Umberto
Environmental Objective Deployment (EOD)	SustainableMinds

Figure 32 - Examples of eco-design techniques and tools (Pigosso *et al.*, 2014)

6.2 ANNEX II

1. New Concept Development

a. dematerialisation; does the user actually need a product, could a service be offered instead (PSS)
b. shared use of product; is the user willing to share the product with others? Is personal ownership important to the user?
c. integration of Functions; can we combine the functions of different products into one product (multiple uses)?
d. functional optimisation of product (components); can modular components be used to create an entire product range?

2. Select Low-Impact Material

a. non hazardous materials; do the materials selected harm the environment?
b. non-exhaustible materials; are the materials selected renewable?
c. low energy materials; are the materials selected energy intensive to produce? Can alternatives be specified?
d. recycled materials; are recycled materials an option for your design?
e. recyclable materials; is it possible to use materials that can be recycled?

3. Reduction of Materials

a. reduction in weight; can you reduce the weight of the product by using less material or lighter materials?
b. reduction of transportation volume; can you reduce the volume of the product to optimise transportation?
c. reduction in the number of materials; can you reduce the volume of the product to optimise transportation?

4. Optimise Production Techniques

a. alternative production techniques; are production techniques available that minimise harm to the environment?
b. fewer production processes; can the product be produced using fewer steps?
c. low/clean energy consumption; can we choose cleaner production methods?
d. low generation of waste; is it possible to produce with reduced waste or re-used waste?
e. few/clean consumables; can consumables be reduced in production or non-hazardous consumables be used?

5. Efficient Distribution Systems

a. less/clean packaging; can we remove the need for packaging, or reduce the amount of packaging required, or use less harmful materials?
b. efficient transport mode; have we chosen the most efficient mode of transportation for the product?
c. efficient logistics; can we improve the logistics?

6. Reduction of Environmental Impact During the Use Phase

a. low energy consumption; can the product be made to do without electricity? Can the energy consumption of the product be reduced?
b. clean energy source; is it possible to use a cleaner energy source?
c. few consumables needed during use; can the use of consumables be reduced?
d. clean consumables during use; is it possible to use less harmful consumables?

7. Optimisation of Initial Lifetime

a. reliability and durability; can the product's reliability be improved?
b. easy maintenance and repair; is the product easy to maintain and repair?
c. modular product structure; is it possible to use standard components to repair the product?
d. classic design; can we improve the fashionable lifespan of the products?
e. user taking care of the product; can we design a product that the user will not likely part from?

8. Optimisation of End of Life Systems

a. reuse of product; is it possible to give the product a second life?
b. remanufacturing/refurbishing; can we fix and reuse the product in an as-new product?
c. recycling of materials; can we recycle the materials used in the product?
d. clean incineration; can the incineration of the product create no harmful emission and waste?

Figure 33 – Eco-design strategies across the lifecycle of the product

6.3 ANNEX III

LPG CYLINDERS REQUALIFICATION WITHIN EU/CEN COUNTRIES							
COUNTRY	15 years acceptance/date	Comments	Type of tests				Authority requests
			Ext. Insp.	Int. Insp.	Pres. test	Others	
AUSTRIA	Yes		Yes		Yes		Quality management system + accordance to EN 1439 and 1440
SWITZERLAND	Yes/1997		Yes		Yes		Accordance to EN 1440. Yearly audit.
GERMANY	Yes	Cylinders manufactured from 1969. Under expertise for oldest cylinders.	Yes	Yes	Yes		Product and operation management system requested
BELGIUM	Yes		Yes	No	Yes	Pneumatic pressure test allowed	Accordance to EN 1439 and 1440. Periodical audit by qualified body. Date of the next requalification on the cylinder
FRANCE	Yes/1984	Cylinders manufactured after about 1960-1965. 5 years interval for older cylinders	Yes	No	Yes	Periodical burst tests on samples. Pneumatic test on camping cylinders	Possibility of self assessment Quality management system + periodical audit
SPAIN	Waiting for a response of the authority						
PORTUGAL	Yes	From date of manufacture for "ε" cylinders. From last requalification date for others.	Yes	No	Yes		
UNITED KINGDOM	Yes		Yes	Yes	Yes/No	Pressure test according to company practices	Accordance to EN 1440
IRELAND	Yes		Yes	Yes	No		None. Professional code of practice in accordance with EN 1440. New or refurbished valve.
ITALY	Possible, but not applied	10 years interval applied	Yes	No	Yes		Accordance to EN 1440 ?
DENMARK	Possible, but not applied	10 years interval applied. 5 years interval for cylinders manufactured before 1956.	Yes	Yes	Yes		Accordance to EU directive 1999/36: Approved quality management system in accordance to 1999/36/EEC or EN 45004. Accordance to EN 1440.
FINLAND	Yes		Yes	Yes	Yes	Not more than 5% loss in weight	Accordance to EN 1440. New valve to be fitted
SWEDEN	No		Yes	Yes	Yes	Not more than 5% loss in weight	Accordance to EN 1440. New valve to be fitted

Figure 34 - LPG STEEL CYLINDERS REQUALIFICATION WITHIN EU/CEN COUNTRIES (ADR) (United Nations, 2015)

6.4 ANNEX IV

ISO 11623:2002(E)

Table 2 — Intervals for steel liners ([a])

Description	Gas ([g])	Period (Years)
Compressed gases	e.g. Ar, Xe, Ne, N_2, CH_4, and compressed gas mixtures	5 or 10 (see [f])
	H_2	5 or 10 (see [e] and [f])
	Air, O_2	5 or 10 (see [b] and [f])
	CO	2,5 or 5 (see [d])
Underwater breathing apparatus	Air, O_2	2,5 (visual) and 5 (full)
Liquefied gases	e. g. CO_2, N_2O and liquefied gas mixtures	5 or 10 (see [c] and [f])
Corrosive gases (to cylinder material)	e. g. Cl_2, F_2, NO, SO_2, HF	3
Very toxic gases $LC_{50} \leq 200$ p.p.m. V/V	e. g. AsH_3, PH_3	3
Gas mixtures	a) All mixtures except b) below b) Mixtures containing very toxic gases	a) Shortest period of any component b) If the toxicity of the final mixture is such that $LC_{50} > 200$ p.p.m. V/V, a 5 or 10 year period shall apply (see Note 6). If the toxicity of the final mixture is such that $LC_{50} \leq 200$ p.p.m. V/V, a three year period shall apply.

[a] Certain requirements may necessitate a shorter time interval e.g. the dew point of the gas, polymerisation reactions and decomposition reactions, cylinder design specifications, change of gas service etc. The compatibility of steel with the gas to be filled shall be checked in accordance with ISO 11114-1.

[b] For cylinders used for self-contained breathing apparatus, the re-test period shall not exceed five years.

[c] The longer test period may be used provided the dryness of the product and that of the filled cylinder are such that there is no free water. This condition shall be proven and documented within the quality system of the filler. If the conditions above cannot be fulfilled the cylinder shall be visually and internally inspected every five years and fully re-tested every 10 years.

[d] The longer test period may be used provided the dryness of the product and that of the filled cylinder are such that there is no free water. This condition shall be proven and documented within the quality system of the filler. If the conditions above cannot be fulfilled the cylinder shall be visually and internally inspected every 2,5 years and fully re-tested every five years.

[e] Particular attention shall be paid to the tensile strength and surface condition of such cylinders. Cylinders not conforming to the special hydrogen requirements specified in ISO 11114-1 shall be withdrawn from hydrogen service. Procedures for change of gas service shall be in accordance with EN 1795 or ISO 11621.

[f] The longer test period can apply for cylinders of known designs and safe experience provided approval has been obtained from the competent authority and the manufacturer.

[g] This list of gases is not exhaustive. Gases shall be categorized in accordance with prEN 13096.

Figure 35 - LPG COMPOSITE CYLINDERS REQUALIFICATION PERIOD (The International Standards Organisation, 2013)