3rd International Conference on Industrial Engineering and Industrial Management
XIII Congreso de Ingeniería de Organización
Barcelona-Terrassa, September 2nd-4th 2009

Cost requirements for clean technology new product lifecycle

Pedro Porras, Javier Conde

Dpto. de Organización de Empresas. Escuela Técnica Superior de Ingeniería Industrial. Universidad Nacional de Educación a Distancia. C/ Juan del Rosal, 12, 28040. Madrid. inbox@pedroporras.com; jconde@ind.uned.es

Keywords: cost requirements, clean technology, product lifecycle.

Summary

Clean Technology (CT) products presence has arisen due to an increasing environmental market demand in most of the industries. Many companies are developing clean technologies to pursue an environmentally friendly lifecycle in their products for their customers.

A cost effective CT product or service is needed according to customer expectations and market competition. Especially it becomes critical when a CT product is being developed for a new market. Sometimes these new technologies have been developed adding additional cost to the product cost structure when it is compared to similar non-CT products. Therefore, reduced cost lifecycle has become a key requirement for CT manufacturers when it comes to conception and design of new products.

A framework is proposed to understand the cost dynamics of singular CT products and why their lifecycle is the main key cost driver. Review is approached methodologically to provide a clear understanding of the requirements and lifecycle interactions for this kind of products.

1. Introduction

Clean technology products presence has arisen due to an increasing environmental market demand in most of the industries. People are becoming more environmental sensitive; therefore many companies are developing clean technologies to pursue an environmentally friendly lifecycle in their products for their customers. Lifecycle became the main driver for these products driven by cost and environmental concerns.

2. Clean Technology products

Pernick and Wilder (2007) describe Clean Technology (CT) products as "a diverse range of products, services, and processes that harness renewable materials and energy sources, dramatically reduce the use of natural resources, and cut or eliminate emissions and wastes". CT is claimed to share similarities with Green Technology or Environmental Technology.

CT can be discussed whether it can be considered in itself a new area of technology or not, which is outside the scope of this research. However its use is widespread in academia and industry. There is a scientific journal in the literature called “Clean Technologies and Environmental Policy” which publishes “papers that aid in the development, demonstration, and commercialization of cleaner products and processes as well as effective environmental policy strategies”. There are also several articles and reports which have been conducted on the topic of CT industry and CT firms (for example: Marcoulaki, E.C. et al. (2000); Pineda-Henson, R. and Culaba, A.B. (2004) and Selwyn & Leverett, (2006)). Finally, the CT can be also understood as a whole industry as it is set by the Environmental Innovations Advisory Group (2006) which states how the CT sector is growing significantly resulting in a new, emerging, industry segment. According to this, Pernick and Wilder (2007) identify eight main CT industries: solar power, wind power, biofuels, green buildings, personal transportation, the smart grid, mobile applications (such as portable fuel cells), and water filtration".

In these eight previous CT industries, products or services are designed to improve the operational performance, productivity, or efficiency while energy consumption, waste, costs, or pollution are reduced.

3. Product cost requirements

IEEE (1996) defines Requirement as "a condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed certification". The identification of needs and creation of a knowledge base to facilitate the efforts during the product conception and development is called Requirements Engineering, which comprises three activities: elicitation, analysis and specification of requirements. In this line, the study of complex mechanical systems lead Kerr et al., (2004) to divide the requirements of the product specification into seven groups: Layout, Structural, Regulatory, Styling, Marketability, Weight and Cost.

It has been suggested that cost is perhaps the most influential factor in the outcome of a product or service within many of today's industries (Roy, 2003). Cost requirements main focus consists on meeting previous defined cost targets for each specific product or service. According to this, cost requirements may include constraints with them; these requirements and their constraints may change and evolve throughout the product lifecycle due to technology, competition and the persistence of organisations to stay ahead (Roy et al., 2005). To perform cost requirements engineering, Firesmith (2002) states three standard activities: cost targets specifications during the project life cycle, change monitoring and management and documents traceability and control alignment between the developed system and the original specification.

Product cost requirements engineering combined with a lifecycle model on product development provides complete impact information of cost related decisions from conception to disposal.

4. Life Cycle Assessment (LCA) methods for clean technology products

The IEEE (2005) defines Product Life Cycle as the product evolution initiated by a perceived stakeholder need through the disposal of the products, including the following stages: conception, design, development, manufacturing, service and disposal. The impact of the product in these stages is analysed by the Life Cycle Engineering technique, where the life cycle cost is the total investment in product design, development, manufacturing, test, distribution, operation, training, maintenance and disposal.

The application of the ISO 14040 standard (2006) allows us to assess the general impact and potential environmental aspects of a product (or service) and each of its subcomponents from a Life Cycle Assessment (LCA) study. It is achieved compiling an inventory of relevant inputs and outputs and evaluating the potential environmental impacts associated with these inputs and outputs. It also allows us to evaluate the factors that produce more impact and the aspects that could be improved in order to reduce the effective impact.

LCA has three components (United States Environment Protection Agency, 1993):

– Inventory analysis: technical data quantification of material and energy requirements, waterborne emissions, atmospheric pollution, solid wastes and other releases within the entire life cycle of a product is achieved.

– Impact analysis: a technical quantitative and qualitative identification and assessment of the effects of the resource requirements and environmental loadings identified in the inventory stage.

– Improvement analysis: links the product lifecycle and its potential impacts.

The results of LCA provide three dimensions to study, determine and monitor those cost requirements related to environmental aspects:

– The Life Cycle Stages: This is the physical sequence of unit processes across the life cycle to evaluate the change and evolution of requirements.

– Analysis of Multiple Environmental and Resource Issues: LCA is not just a single issue approach; it considers the tradeoffs across many environmental concerns and different alternatives to provide informed decisions for the best identification, evaluation and fulfilment.

– Assessment: LCA extends beyond the quantitative analysis to a point where an evaluation or judgment is made. At its simplest, this may be a statement of what is better and what is worse as requirements management support.

The reduction of energy consumption, waste, costs, or pollution is the reason for CT products. If the product impact on energy consumption, waste or pollution can be transformed as cost structures in the final lifecycle, Durairaj et al. (2002), they can be identified with cost requirements to meet initial and lifecycle cost targets.

LCA and implemented cost analysis models provide information of the relationships between cost and design parameters. They contribute to cost reduction by identifying high cost contributors (Martínez, E. et al., 2009). As a result, there are many requirements and features of a product that can be studied using a Life Cycle Cost Analysis (LCCA) model. (Durairaj et al., 2002).

LCCA is a systematic analytical process for evaluating various designs or alternative courses of actions with the objective of choosing the best way to employ scarce resources. Its target is to reduce the total cost evaluating different green or eco-friendly alternatives in all the stages of the life cycle. According to Fabrycky W.J. and Blanchard B.S (1991) the ultimate objective of the LCCA of any product is to provide a framework for finding the total cost of design and development, production, use and disposal of the product with an intention of reducing the total cost.

The last model called "Life Cycle Environmental Cost Analysis (LCECA)", proposed by Durairaj et al., (2002), includes and differentiates eco-costs within the total cost structure of a product. This model also considers cost effective alternatives for specific requirements in CT products.

These assessments are summarised as follows:

LCA: Life Cycle Assessment	Assesses the general environmental impact of a product.
LCCA: Life Cycle Cost Analysis	Evaluates alternative environmental designs to reduce costs.
LCECA: Life Cycle Environmental Cost Analysis	Differentiate eco-costs in the total cost structure of the products.

5. Cost requirements interactions with Life Cycle Environmental Cost Analysis Model

Life Cycle Environmental Cost Analysis (LCECA) model proposed by Durairaj et al., (2002) identifies eco-costs from potential environmental impacts of the product and product subparts. These eco-costs are integrated in the total cost structure of the products. As example of a set of eco-cost, the following list is presented:

- Cost of effluent control.
- Cost of effluent treatment.
- Cost of effluent disposal.
- Cost of implementation of environmental management systems.
- Costs of eco-taxes.
- Costs of rehabilitation.
- Costs of energy.
- Cost savings with cleaner alternatives…

These are so called eco-costs which will be identified as sources for modified cost requirements.

Martínez, E. et al. (2009) provides a comprehensive LCA of the environmental impact of a power wind turbine, which is a perfect example of CT product. As shown in figure 1, a relationship between product components and environmental impact is established. These environmental impacts can be transformed into costs to be compared with non-CT products in terms of efficiency and operational performance.

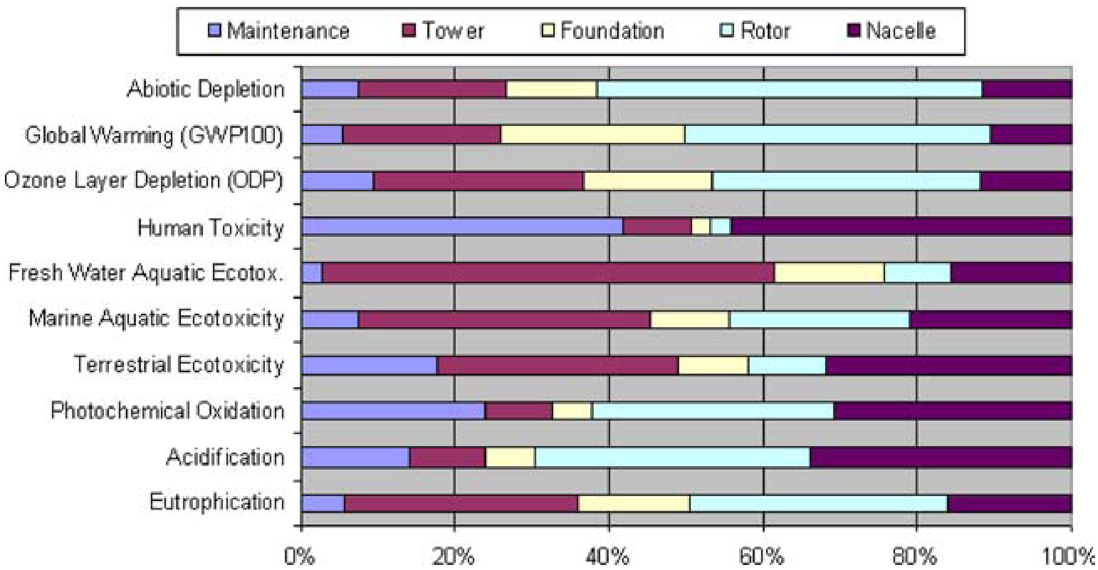

Figure1: Relationship between product components and their environmental impact (Martínez, E. et al., 2009)

Martínez, E. et al. (2009) develops a life cycle inventory (LCI) data for the main components of the product, collecting information regarding energy and material consumption, disposal, pollution and environmental effects in all stages, paying specific attention to manufacturing, service and recycling processes. Finally, the related cost of each data is calculated to proceed with the evaluations and comparisons of alternatives.

6. Integrated cost requirements modelling

Life cycle issues can be fundamentally prevented in the early stages of design and new product development, because, when a product is being developed, the cost constraints must be satisfied by all different approaches studied by designers. But this is only possible when they can determine the lifecycle impact of their decisions as they make them (Roy, R.; 2000). The Integrated Product Development (IPD) method, see figure 2, has demonstrated its validity for life cycle sensitive approaches.

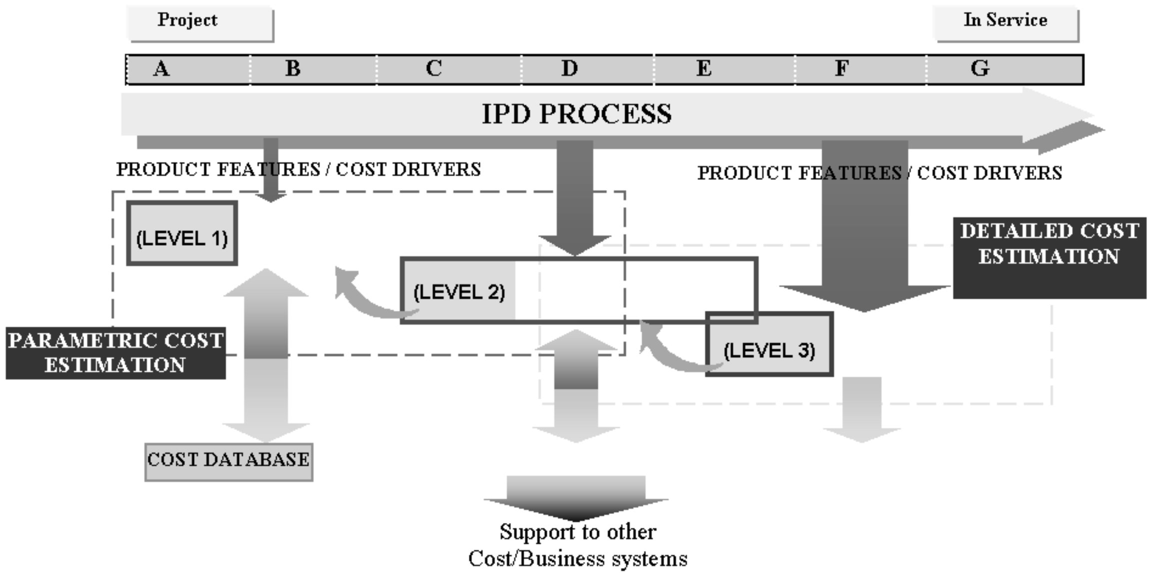

Figure 2: Integrated cost modelling (Rush and Roy, 2000)

The Integrated Product Development (IPD) method is a requirements based approach which can be constantly used throughout all the lifecycle engineering phases giving support and sharing data with other cost or business related systems.

In the first phases of the life cycle, parametric cost estimation is more common and shares information with a cost database. Decisions are moving the project to higher levels of definition where the estimation is more detailed. Cost drivers provide significant restrictions to the cost requirements structure and their impacts are significantly interconnected.

7. Cost requirements framework considering eco-costs input

There is a need to identify a systematic approach of the cost requirements creation from a designer perspective in new CT products with a lifecycle sensitive standpoint. The following framework, shown in figure 3, is proposed comprising the complete product lifecycle analysis, where eco-costs are transformed into costs requirements, defining the technology as "clean".

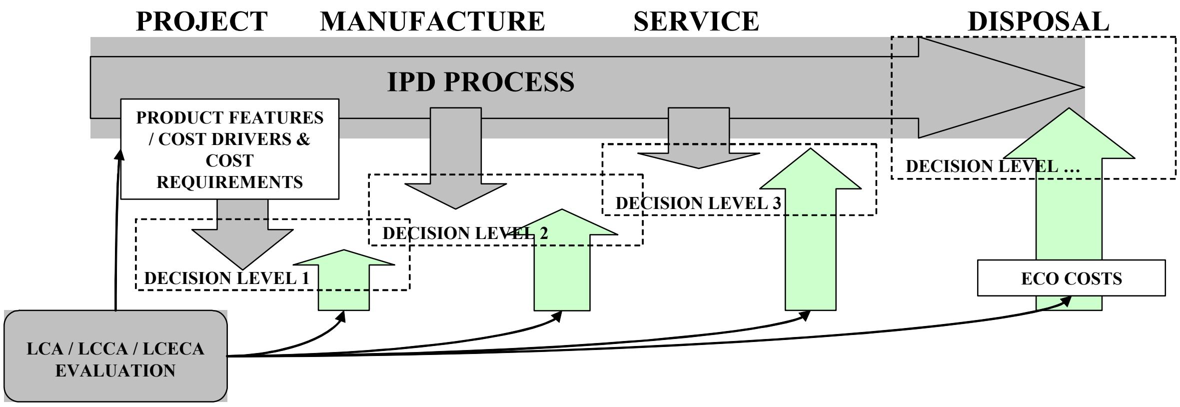

Figure 3: Life Cycle Assessment Methods designed to define new cost requirements including Eco-costs.

LCECA provides the identification of eco-costs associated with LCA environmental impact and the cost structure of the product. LCCA provides the alternatives to reduce the cost and the eco-costs, maintaining the environmental approach of the technology designs. Design engineers provide product features for the product requirements definition. Cost engineers study the cost drivers of the product and with estimations build up the product cost structure. Design and cost estimation activities receive input from LCECA conclusions in CT products. As a result the eco-costs are evaluated as any other potential cost driver.

Cost requirements are developed according to the conditions imposed by product specifications cost estimations, budgets and cost drivers. Cost drivers include eco-costs with an important role in CT products design.

The ongoing reductions of these eco-costs are the main drivers for the conception and development of CT products. Therefore CT products can be considered as those with the lowest life cycle cost including eco cost compared others designed for the same purpose. This is the reason of existence of the LCA LCCA and LCECA methods as the public became sensitive to environmental issues. So, as a result, the main cost requirement for a CT product is the whole life cycle cost (including eco-costs).

These eco-costs provide a comparable understanding of the characteristics of clean new products in terms of efficiency, as product usability is equal while there are cost savings selecting alternative environmental designs.

The missing step between eco-costs and cost requirements definition has been identified in the LCCA and LCECA. These assessments are updated according to the ongoing Integrated Product Data process along the complete life cycle of the product (see figure 4).

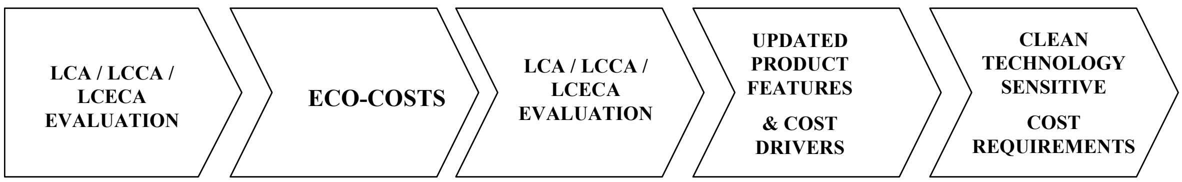

Figure 4: Cost requirements development, sensitive to CT aspects.

8. Validation

Informal interviews were conducted with design engineers, cost engineers and sales engineers to validate this research. Open questions and real experiences were discussed to prove the usability and real application of the proposed framework. Suggestions were used to define the final layout of the figure 3 which attracted the attention of some interviewees to introduce slight modifications.

All the interviewed engineers agreed with the model and how the relationship between eco-costs and cost requirements where exposed as initial constraints to develop new CT products. Especially the design engineer and sales engineers agreed on the reduced lifecycle cost oriented launch of new products.

9. Conclusions and suggested future research

A framework for CT new products development and their environmental lifecycle cost impact understanding has been proposed. The definition process of cost requirements through LCCA iteration with eco-costs inputs has been identified and their significance throughout the new product conception and development was revealed.

These eco-cost drivers outline a practical methodology to understand the characteristics of CT new products in terms of efficiency, compared savings and product usability.

Lifecycle cost has been found to be the main design cost driver for CT products within the presented framework, taking into consideration eco-costs. The conception of new CT products has been observed to be lifecycle cost reduction oriented.

Future research should be oriented to the comparison of the weight of eco-costs between products of different industries. The study of particular tools integrating live updates of environmental assessments would be interesting in products where service related eco-costs have a more significant impact.

References

Durairaj, S.K.; Ong, S.K.; Nee, A.Y.C.; Tan, R.B.H. (2002). Evaluation of Life Cycle Cost Analysis Methodologies. *Corporate Environmental Strategy*, Vol. 9, No. 1.

Environmental Innovations Advisory Group (2006), Environmental innovation: bridging the gap between environmental necessity and economic opportunity. First report of the environmental innovations advisory group, Department of Trade and Industry (DTI) in association with Department of Environment Food and Rural Affairs (Defra), London.

Fabrycky, W.J.; Blanchard, B.S. (1991), Life Cycle Cost and Economic Analysis, Prentice Hall, Englewood Cliffs, NJ, 1991.

IEEE Std 1233-1996. IEEE Guide for Developing Systems Requirements Specifications. 1996.

IEEE Std. 1220-2005. ISO/IEC 26702. Systems engineering, Application and management of the systems engineering process. International Standard 2005.

ISO 14040 (2006): Environmental management - Life cycle assessment -Principles and framework, International Organisation for Standardisation (ISO), Geneve.

Kerr, C. I.; Roy, R.; Sackett, P. J. (2004), "Designing through the supply chain: A requirements perspective", *3rd International Conference on Total Vehicle Technology (TVT 2004)*, Brighton, United Kingdom, April 26-27.

Marcoulaki, E.C.; Kokossis, A.C.; Batzias, F.A. (2000), Novel chemicals for clean and efficient processes using stochastic optimization. *Computers and Chemical Engineering*. Vol. 24. pp. 705-710.

Martínez, E.; Sanz, F.; Pellegrini, S.; Jiménez, E. and Blanco, J. (2009). Life-cycle assessment of a 2-MW rated power wind turbine: CML method. *International Journal of Life Cycle Assessment,* Vol.14, pp. 52–63.

Oduguwa, P.A.; Roy, R.; Sackett, P.J. (2006). Cost Impact Analysis of Requirements Changes in the Automotive Industry. *Proceedings of the Institution of Mechanical Engineers Part B. Journal of Engineering Manufacture*, Vol. 220, pp 1509-1525.

Pernick, R. and Wilder, C. (2007). The Clean Tech Revolution. Collins, ISBN 978-0060896232, 2008.

Pineda-Henson, R. and Culaba, A.B. (2004). A Diagnostic Model for Green Productivity Assessment of Manufacturing Processes. *International Journal of Life Cycle Assessment*, Vol. 9, No. 6, pp. 379-386.

Roy, R. (2003), Decision Engineering Report Series, Cranfield University, Cranfield, UK.

Roy, R.; Scott, S.; Griggs, T. (2005). Estimating the Cost of a New Technology Intensive Automotive Product: *A Case Study Approach. International Journal of Production Economics,* Vol. 97, Issue 2, pp. 210-226.

Rush, C. and Roy, R. (2000) Analysis of cost estimating processes used within a concurrent engineering environment throughout a product life cycle. *Proceedings of CE2000 Conference*, Lyon, France, July 17-21, 2000, pp. 58-67.

Selwyn, J. and Leverett, B. (2006), Emerging markets in the environmental industries sector November 2006, UK Centre for economic and environmental development and Department of trade and industry (DTI), London.

United States Environment Protection Agency, Life Cycle Assessment: Inventory guidelines and Principles, Washington D.C, 1993.