Investigating the use of TRIZ in Eco- innovation

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1. Introduction

This paper aims to identify ways in which tools and methodologies from TRIZ might be used in Eco-Innovation and subsequently how TRIZ might be adapted for that specific purpose.

Eco-innovation is the process of developing new products, processes or services which provide customer and business value but significantly decrease environmental impact (James, 1997). Eco-innovation is one of several approaches towards sustainable design.

The authors became interested in TRIZ after identifying some overlap in the philosophies of TRIZ and sustainable design. Sustainable design is one part of a global movement towards sustainable development which is driven by the realisation that society cannot continue current modes of production and consumption without serious ecological damage. One commonly quoted definition of sustainable development is 'development which meets the needs of a current generation without compromising the ability of a future generation to meet their needs' (the Bruntland Commission, 1987). One fundamental concept of TRIZ is that all systems will evolve towards an increased degree of ideality: an ideal system being one that does not exist but its function is delivered (Salamatov, 1999). Innovation following this law of ideality could contribute to sustainable development, through the delivery of the functions without the environmental impacts associated with current systems of production.

First, the authors looked briefly at the overlap between one Eco-Innovation tool (the Eco-compass) and one TRIZ tool (the contradiction matrix). From this part of the study the authors identified one way in which TRIZ might be adapted for use in Eco-Innovation.

TRIZ shows how it is possible to develop useful innovation tools by extracting generic principles from patents. The second approach taken by the authors was to study the patents of environmentally designed products currently available. These environmentally designed products are referred to as 'Eco-innovation exemplars'. This paper reports on the development of energy efficient lighting and presents a detailed study of a chosen 'Eco-innovation exemplar' patent from fluorescent tube lighting. From this part of the study the authors gained several insights into the ways in which TRIZ might be used in Eco-Innovation.

2. Two approaches to sustainable design: Ecodesign and Eco-Innovation

2.1 Eco-design and business example Philips

Ecodesign aims to reduce the environmental impact of the product throughout its life cycle: from materials extraction, through production processes, packaging and transport, product use phase, and finally to end-of-life disposal. Ecodesign includes the use of quantitative environmental analysis tools such as Life Cycle Analysis (LCA) tools. The results from Ecodesign are limited because it is a design specific activity that focuses on the redesign or optimisation of **existing** products. The changes to the products tend to be incremental and result only in percentile reduction of the overall environmental impact of the products (Hoed, 1997).

However Ecodesign can improve a company's competitive advantage by supporting expansion into new markets, through the launch of new versions of products with environmental attributes which consumers desire. Philips for example launched a range of ‘green products’ in 1998 (Philips Electronics, 1998) and has had corporate environmental commitment since 1987 when they issued their first environmental policy. They have long regarded environmental care as a business opportunity, where the corporate ‘Green Image’ is of great value to the compnay both externally and internally (Meinders, 1999). Such an environmentally proactive company may also benefit financially from the optimisation of production processes, reduced material use, and reduced waste generation.

2.2 Eco innovation and business example Electrolux

Eco-innovation is one step beyond Ecodesign and aims to develop **new** products and services that are not based on redesign or incremental changes to the existing product but rather on providing the consumer with the **function** that they require in the most Eco-efficient way. Examples of such function-oriented redesign are solutions that ‘dematerialise’ the product and replace it by a service. An example of such a ‘product to service shift’ is a network based telephone answer service, which is replacing electronic answering machines. These telephone answer services are accessed by a standard telephone and require no other hardware in the home, thereby removing the production, materials, packaging and logistics impacts of the electronic product. Current environmental research programs are investigating the impact of these product to service shifts (Low, IEEE, 2000).

A second example of a product to service shift is the launch of a new business pilot scheme from Electrolux on the island of Gotland in Sweden (Electrolux, [http://193.183.104.77/node323.asp], 2000). They have called it Functional Sales (see figure 1), and together with the energy utility company Vattenfall, Electrolux offers a pay-per-wash option for the participants' laundry needs. Customers do not buy their washing machine but do have one in their home. Customers are paying for only the “**function**” of Clean Clothes; they are paying for the number of usages. This creates incentives for customer to reduce the number of usages and thereby reduce the energy and detergent consumption. Customers can choose to upgrade to washers with larger capacity.

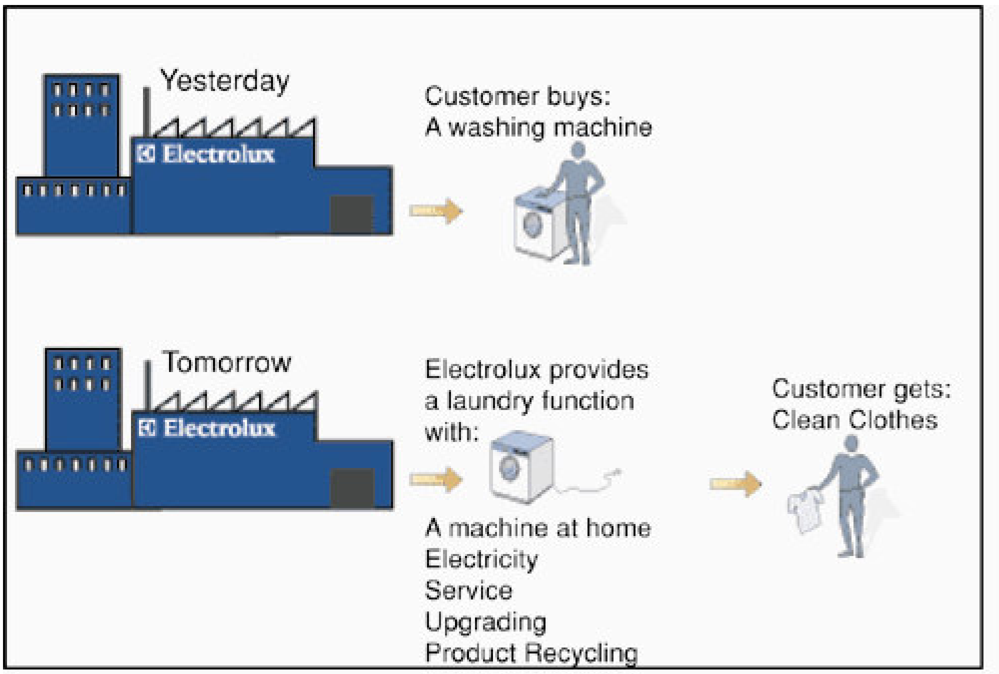


Figure 1: Electrolux functional sales, after Electrolux, [http://193.183.104.77/node323.asp], (2000)

This type of product to service shift could have significant effects on the way the product is designed. To suit these business models, companies will have to design their products with increased endurance, serviceability and refurbishment capability which, in turn, will reduce the products overall environmental impact. These business models may well spread to other areas and may change the way we design our appliances in the future.

3. An Eco-Innovation tool in relation to contradiction matrix

3.1 The Eco-compass

A number of tools have been developed to support the process of Eco-innovation such as the Life-cycle Design Strategy (LiDS) wheel (Brezet et al., 1996) and the Eco-compass (Fussler & James, 1996). Both these tools condense environmental information and provide 'streamlined' methods to compare the environmental merits of a new proposal against the original design.

The Eco-compass (Fussler & James, 1996) is one of the most successful streamlined Eco-innovation tools. The Eco-compass was designed to condense environmental data into a simple model, which would assist in the integration of environmental issues within the business decision process.

The compass has six poles or 'axes', which are intended to represent all significant environmental issues (see Figure 2): mass intensity, reducing human health and environmental risk, energy intensity, reuse and revalorization of wastes, resource conservation and extending service and function.

The Eco-compass is a comparative spider diagram, which evaluates new options or designs against the original design or 'base case'. Each of the axes records a score from 0-5 for the new product. The base case always scores 2 in each dimension and the new option can score from 0 (environmental impact doubled) to 5 (environmental impact reduced by at least factor 4).

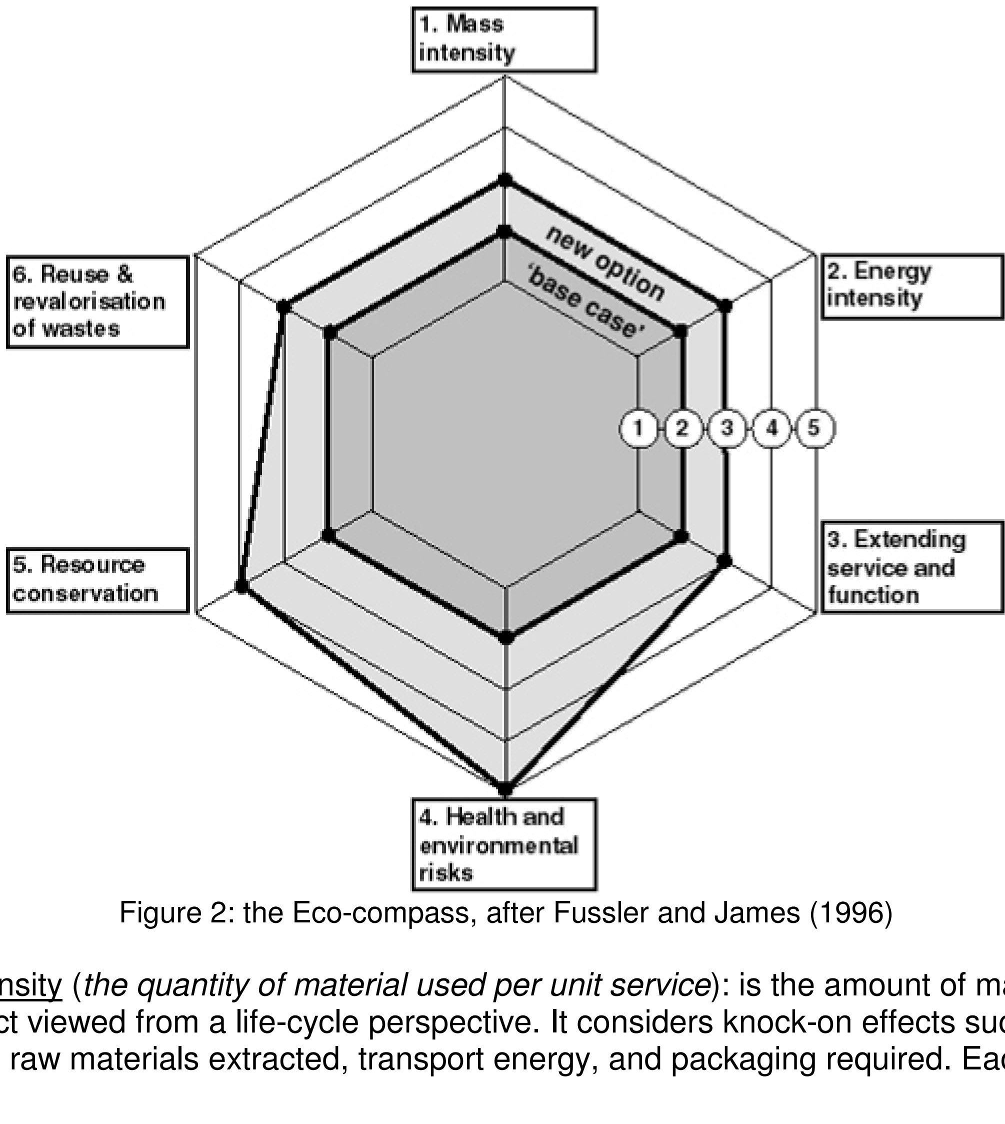


Figure 2: the Eco-compass, after Fussler and James (1996)

<u>Mass Intensity</u> (*the quantity of material used per unit service*): is the amount of materials in the product viewed from a life-cycle perspective. It considers knock-on effects such as: amount of raw materials extracted, transport energy, and packaging required. Each

material used in the product has a hidden material ‘rucksack’ of environmental effects such as erosion, earth displacement and waste of unconverted materials.

Energy Intensity (*quantity energy used per unit service*): is the energy consumption at all stages of the product’s lifetime. The production and consumption of energy produces pollution and waste materials. When derived from fossil fuels energy production depletes non-renewable resources as well as generating carbon dioxide emissions.

Extending Service and Function (*increasing quantity of functional units in the product*): considers ways of delivering more service to customers from a given amount of environmental inputs. This can be achieved by increasing product: durability, reparability, upgradeability, multi-functionality or shared use of the product.

Health and Environmental Risk (*quantity of hazardous substances emitted to air soil and water*): Toxicologists try first to identify the ways in which a product or process creates health and environmental risks. Secondly, to consider the importance of the risk identified. Identifying hazardous substances and setting reduction targets is an ongoing process. Eco-innovation helps to meet these targets.

Resource Conservation (*quantity of scarce or depleting resources used*): Focuses on the nature and re-newability of the energy and materials needed for a product or process. It considers the overall impact of specific resource needs.

Revalorization (*quantity of waste not Eco-efficiently recycled*): includes several different approaches to waste. The main aim is to close the loop on materials and products by recycling (converting wastes back into raw materials) re-use and remanufacturing (refurbishment of complete products or components).

3.2 TRIZ parameters compared to Eco-compass headings

In this part of the study the authors compared the axes of the contradiction matrix (the ‘engineering parameters’) and the headings on the Eco-compass axes. The headings from the Eco-compass were chosen because they provide a simple, condensed model for Eco-innovation(Jones et al., 1999). Although TRIZ consists of many sophisticated innovation tools , the contradiction matrix was chosen in order to become acquainted with TRIZ fundamentals.

Studying the axes of the contradiction matrix or the ‘engineering parameters’ revealed that there are engineering parameters covering several of the headings on the Eco-compass axes (See figure 3). However, it also revealed that the Eco-innovation issues: Health and environmental Risk, Revalorization and Resource Conservation, are only blanket covered under the engineering parameter ‘harmful-side effects’.

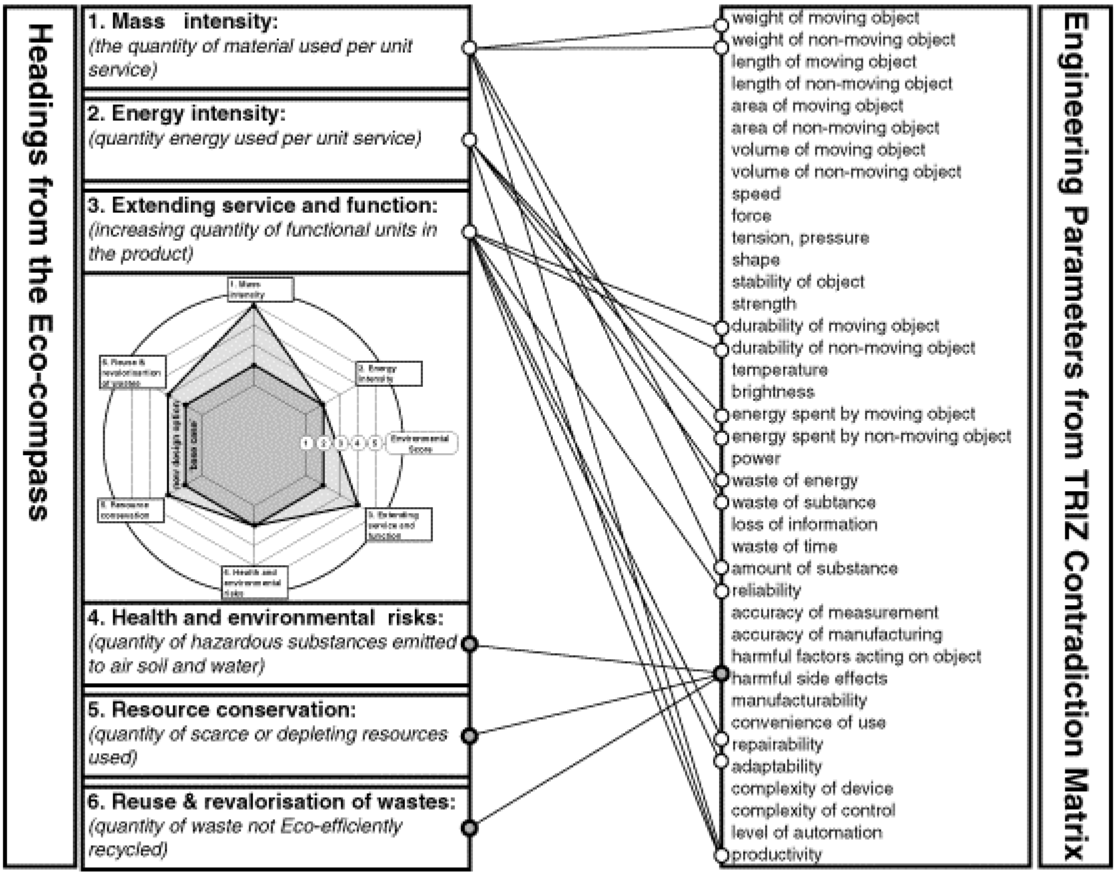


Figure 3: comparing Eco-compass headings and TRIZ parameters

4. Case study of current best-practise Eco-Innovation: the development of energy efficient lighting

In this part of the study the authors wanted to study a collection of best available environmentally designed products which we have called 'Eco-innovation exemplars'. The sunbject chosen was energy efficient lighting. Without any sophisticated patent searching software the authors needed to study the development of energy efficient lighting to be able to select the most relevant products and select a limited time span over which to study their patents.

4.1 The CFL and innovation

The authors wanted to select the most relevant product in energy efficient lighting and immediately thought of the compact fluorescent lamp (CFL). CFLs use a quarter of the amount of energy for the same unit function as a standard incandescent light bulb and have at least a 10 times longer service life.

Figure 4: shows a typical CFL, after Philips, [http://www.eur.lighting.philips.com], (2000)

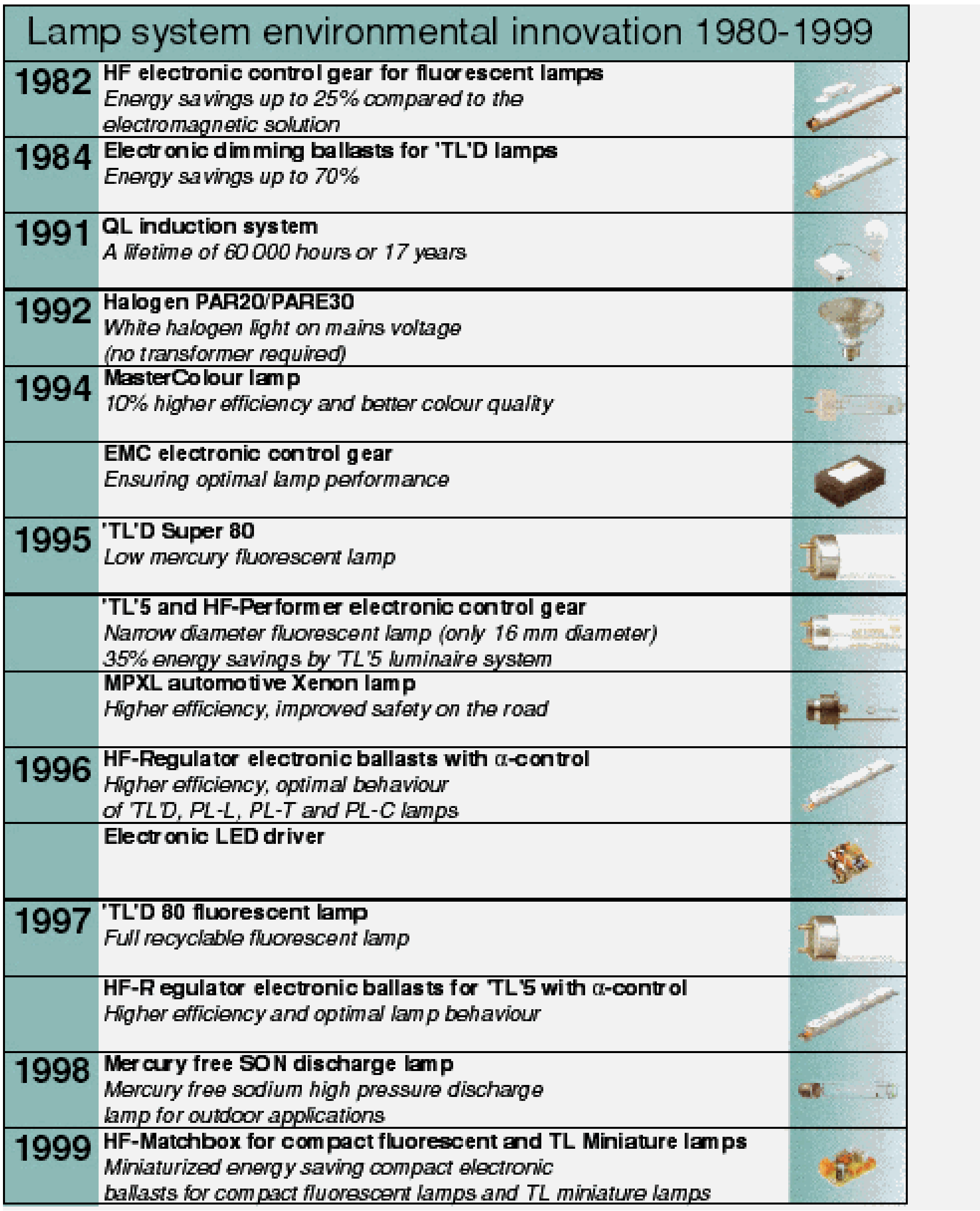
The following example of the replacement of the incandescent light bulb, with Compact Fluorescent Lamps (CFL) was published by Weizsacher et al. (1997):

The Global market currently consumes 10.000 million incandescent light bulbs per year. 200 million CFL were sold in 1994 and the figures are steadily rising by 15-20 % each year. These light bulbs last 10 times longer, which means that they are effectively replacing 2000 million incandescent light bulbs. The replacement of one 75W with an 18W compact fluorescent can, over its lifetime, save: at least energy value of 200 litres of oil for oil fired electricity production.

From studying the development of lamp technologies the authors found there were many environmentally relevant innovations in ordinary fluorescent tube lamps. CFLs were often secondary adopters of technologies such as the improved phosphors and high frequency dimmable ballasts. For these reasons conventional fluorescent tube lighting was chosen as the product for the rest of this study.

4.2 Environmental innovations in fluorescent tube lighting

Philips Lighting make products in all the different lamp technologies. Figure 5 charts their most relevant environmental innovations from 1980-1999 and shows that half of those innovations are in fluorescent tube lighting (Philips Lighting Europe, 2000). Both our technology study and this chart show an interesting period in environmentally relevant innovations for the fluorescent tube lamps. We decided to search for patents on fluorescent tube lighting 1970-2000.



Lamp system environmental innovation 1980-1999	
1982	**HF electronic control gear for fluorescent lamps** *Energy savings up to 25% compared to the electromagnetic solution*
1984	**Electronic dimming ballasts for 'TL'D lamps** *Energy savings up to 70%*
1991	**QL induction system** *A lifetime of 60 000 hours or 17 years*
1992	**Halogen PAR20/PARE30** *White halogen light on mains voltage (no transformer required)*
1994	**MasterColour lamp** *10% higher efficiency and better colour quality*
	EMC electronic control gear *Ensuring optimal lamp performance*
1995	**'TL'D Super 80** *Low mercury fluorescent lamp*
	'TL'5 and HF-Performer electronic control gear *Narrow diameter fluorescent lamp (only 16 mm diameter) 35% energy savings by 'TL'5 luminaire system*
	MPXL automotive Xenon lamp *Higher efficiency, improved safety on the road*
1996	**HF-Regulator electronic ballasts with α-control** *Higher efficiency, optimal behaviour of 'TL'D, PL-L, PL-T and PL-C lamps*
	Electronic LED driver
1997	**'TL'D 80 fluorescent lamp** *Full recyclable fluorescent lamp*
	HF-Regulator electronic ballasts for 'TL'5 with α-control *Higher efficiency and optimal lamp behaviour*
1998	**Mercury free SON discharge lamp** *Mercury free sodium high pressure discharge lamp for outdoor applications*
1999	**HF-Matchbox for compact fluorescent and TL Miniature lamps** *Miniaturized energy saving compact electronic ballasts for compact fluorescent lamps and TL miniature lamps*

Figure 5: Philips lamp system environmental innovation 1980-1999, after Philips Lighting Europe, (2000)

4.3 Patent profile fluorescent tube lighting 1971-1999

Figure 6 shows the collection of patents studied. From the patent abstracts it was possible to deduce the main benefits of each innovation. The authors assessed the extent to which the innovation results in changes in quantities of:

material used per unit service;

energy used per unit service;

hazardous substances emitted to air soil and water;

waste not Eco-efficiently recycled;

scarce or depleting resources used;

functional units in the product.

Each potential environmental 'value' improvement described in the patent was marked with an X.

From the table it is possible to observe a shift in innovation focus.

Until the mid ‘80s the patents mainly record:

the optimisation of the bulbs production: (column 1: reduction in the mass of materials used);

increasing competitive performance (column 6: Longer lamp lives are classified under ‘increased functional units in the product’, column 2: increasing energy efficiency).

From 1985 onwards the patents start to record developments in:

recycling processes (column 4):

reducing toxicity (column 3).

There were no innovations listed that specifically avoid the use of scarce or depleting resources (column 5).

			Eco-innovation headings					
			material used per unit service	energy used per unit service	hazardous substances emitted	waste not Eco-efficiently recycled	scarce ordepleting resources used	functional units in the product
1971-05-25	US3581139	Fluorescent lamp having Titanium Dioxide-containing glass envelope and reduced phosphor weight	X					X
1971-08-31	US3602758	Phosphor blend lamps which reduce the proportions of the costlier phosphors						
1972-12-26	US3707642	Vapor lamp which incorporates a special phosphor coating	X					
1975-05-27	US3886396	Fluorescent lamp with a protective coating						X
1976-02-10	US3937998	Luminescent coating for low-pressure mercury vapour discharge lamp		X				
1976-06-29	US3967153	Fluorescent lamp having electrically conductive coating and a protective coating therefor						
1978-03-14	US4079288	Alumina coatings for mercury vapor lamps			X			
1978-05-09	US4088923	Fluorescent lamp with superimposed luminescent layers						
1978-06-20	US4096088	Method of preparing cerium and terbium activated aluminate phosphors						
1979-04-17	US4150321	Luminescent aluminates and mercury vapor discharge lamp containing the same		X				
1982-12-14	US4363998	Fluorescent lamp processing which improves performance of zinc silicate phosphor used therein		X				
1984-05-08	US4447756	Fluorescent lamp with layer of plural phosphors having different particle sizes	X					
1985-01-08	US4492898	Mercury-free discharge lamp						
1989-08-22	US4858833	Process for recycling fluorescent and television tubes				X		
1990-04-10	US4916359	Gas discharge lamp envelope comprising a barium sulphate protective layer disposed on its inner surface		X				X
1991-12-05	DE4030732	Processing fluorescent lamp scrap - for recycling of glass, mercury phosphor, and metals avoiding waste and pollution			X	X		
1992-03-03	US5092527	Fluorescent tube crusher with particulate separation and recovery			X			
1992-04-21	US5106598	Lamp reclamation process				X		
1992-12-08	US5170095	Low-pressure mercury vapor discharge light source of high wall loadability						X
1993-07-20	US5229687	Mercury vapor discharge lamp containing means for reducing mercury leaching			X			
1993-07-27	US5230140	Process for environmentally safe disposal of used fluorescent lamp potted ballast assemblies with component reclamation			X			
1994-11-01	US5360169	Process and apparatus for the disposal of articles containing metals or metal vapors			X			
1995-02-14	US5388773	Crushed fluorescent tube particulate separation and recovery method and apparatus				X		
1996-09-03	US5552665	Electric lamp having an undercoat for increasing the light output of a luminescent layer		X				
1996-09-10	US5553708	Packaging for shipping spent fluorescent lamps			X	X		
1999-04-06	US5890940	Lamp recycling apparatus and method for doing the same			X			
1999-04-27	US5898265	TCLP compliant fluorescent lamp			X			X
1999-10-13	EP0949016	Method for treating used fluorescent lamps to recover the glass tubes				X		

Figure 6: shows the patent collection and the potential environmental improvements resulting from each.

4.4 Detailed patent study of a fluorescent tube lamp

Having compiled the patent profile of fluorescent tube lighting, the authors wanted to get an insight into the type of contradictions solved in environmentally relevant patents. To do this, such patents would need to be studied in more detail. This section reports on the first of these more detailed patent studies.

The patent chosen from the patent profile fluorescent tube lighting was US5898265: Toxic Characteristic Leaching Procedure (TCLP) compliant fluorescent lamp. The TCLP test is a toxicity test established in 1990 by EPA to prevent large quantities of heavy metal going to landfill. The patent records a combination of innovations that lead to environmental (TCLP) compliance for a fluorescent tube lamp, and must therefore contain environmentally relevant innovations. The patent describes the reduction of the total mercury content by more than 80% (factor 4) whilst providing a lamp-life and photometric quality comparable to other commercially available fluorescent lamps. These lamps no longer pose danger in landfill and can be safely disposed of in landfill whilst also still being 100% recyclable, a more expensive disposal option. Competitors' lamps often use mercury-binding agents that 'cheat' the TCLP test.

Press releases from the patent owners (Philips, [http://www.eur.lighting.philips.com], 2000) and product brochures of the fluorescent tube lamps 'Alto' and 'TL'D Super 80' supplemented the information contained in the patent. These helped the authors understand the environmental benefits of the innovations described in the patent.

4.5 Breakdown of patent showing the 'Environmental contradiction' and solutions hierarchy

From the patent it was clear that the company had made a strategic commitment to try to develop a lamp that would pass the TCLP test without cheating whilst still producing a lamp that would be competitive. In real terms this meant that, to pass this test they would have to reduce the mercury content of standard fluorescent tubes by at least 75% whilst achieving an energy efficient, 20.000 hour lamp life.

From the company's strategic point of view the 'Environmental contradiction' was between remaining competitive in the lighting market and complying with environmental legislation without cheating. Figure 7 shows the 'Environmental contradiction' that the company was trying to solve between lamp performance characteristics and harmful materials in lamps.

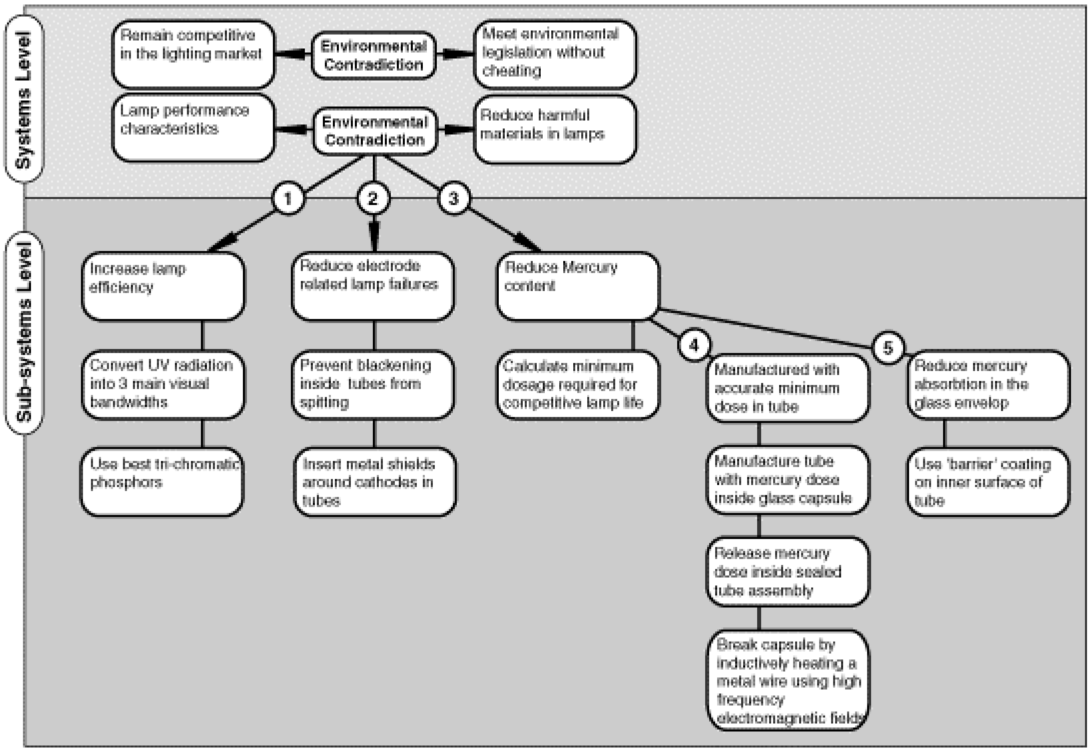


Figure 7 breakdown of patent US5898265.

The lamp's life-time is affected by mercury absorption in the glass envelope over time, electrode failure and tube blackening from spitting electrodes. The lamp's energy consumption is affected by the efficiency of the phosphors to convert the UV radiation into visible light. Figure 7 shows the combined approach described in the patent which addresses all these performance factors (see columns 1,2 and 5).

The use of the best tri-chromatic phosphors that efficiently convert the UV radiation into three main bandwidths of visible light, namely, red, green and blue.

The small metal shields around the cathodes inside the tube catch the spitting from the cathodes that otherwise cause the tube to blacken and thereby shorten its life.

Over time the amount of mercury vapour inside the bulb slowly decreases due to its absorption in the phosphor layers and the glass envelope. Special 'barrier' coatings help to reduce this effect.

The most innovative part of the patent is shown in column 3 and 4 of figure 7. Traditionally lamps have always been overdosed with mercury. This was done because the actual mercury absorption rates in the tube were unknown and manufacturing techniques were inaccurate. This patent describes the method for calculating the minimum mercury dosage required for competitive lamp life and a novel manufacturing method that accurately inserts that minimum dose in the tube (see columns 3 and 4).

The extremely low dose of mercury is accurately inserted in the tube by containing it within a small glass capsule, which is mounted on one of the end guards in the tube. There is a metal wire encircling this glass capsule. After the production of lamp is complete, the sealed glass capsule is heated inductively by a high frequency electromagnetic field which causes the wire to cut the glass capsule and release the mercury into the tube.

4.6 TRIZ in this patent

From studying the abstract of the patent, the innovation could be defined as the solution to the contradiction between the following parameters: ' harmful side effects' (the mercury in land fill from fluorescent tubes) and 'durability of a non-moving objects' (achieving a competitive lamp-life for the product).

Studying the patent in more depth revealed that several inventions are brought together in this patent. These innovations solve contradictions between other parameters including 'brightness', 'waste of substance', 'amount of substance', and 'accuracy of manufacture'.

The novel manufacturing method described in section 4.5 uses the following of the 40 inventive principles described in TRIZ:

<u>No. 7 Nesting:</u> of the glass capsule inside the tube envelope;

<u>No.28 Replace Mechanical:</u> to break the capsule a high frequency electromagnetic field was used;

<u>No. 37 Thermal Expansion:</u> the difference in the coefficients of heat expansion of the metal wire and the glass capsule cause mercury to be released.

5. Discussion

The patent studied (see figure 7), shows that the environmental issues are present at the systems level of the problem hierarchy. This supports other sources in Eco-innovation that emphasise the need for top-down management commitment for Eco-innovation (Cramer & Stevels, 1997).

As we move down into the problem hierarchy the environmental element disappears. The problems are ordinary technical problems that could be defined as conventional technical or physical contradictions.

Looking closely at the patents studied reveals that, the innovations described in the patents all concern redesign or optimisation of existing lighting products and therefore should only have been only be defined as '**Eco-design** exemplars' (see section 2). It will be much more difficult to find patented products which would be true 'Eco-innovation exemplars'.

5.1 How TRIZ might be used in Eco-innovation

Technical or physical contradiction solving through the use of Existing TRIZ tools such as the 40 principles, SU field analysis, 76 standards or the separation principles could help generate **new** solutions to problems encountered in sustainable design.

The TRIZ principle of ideality and the 20 defined trends of evolution for technical systems could help existing technical systems evolve towards ideality, where the functions of that system are delivered without the environmental impacts currently associated. In a follow up paper the authors will show how SU field analysis can be used to evolve the fluorescent tube one step further along its evolutionary path towards ideality.

The TRIZ principle of problem solving without compromise could contribute to sustainable design. TRIZ identifies the 'core' problems through the definition of contradictions that are to be solved. This aspect of TRIZ may help to prevent typical 'add-on' or 'end-of-pipe' solutions, not desired in Eco-innovation.

5.2 How TRIZ might be adapted for use in Eco-innovation

By studying many more patents of innovative, environmentally designed products it might be possible to extract some generic 'principles' or 'operators' for solving environmental contradictions. Because the environmental contradictions are present on the systems level, these operators for Eco-innovation will most likely support strategic environmental product management. If carried out, this work might contribute to the development of TRIZ in a non-technical context, as is currently investigated by other authors (Mann, 2000).

From studying the 'engineering parameters' of the contradiction matrix the authors would like to see the following three environmental issues covered more explicitly: Health and environmental Risk (hazardous substances emitted to air soil and water), Revalorization (waste not Eco-efficiently recycled) and Resource Conservation (scarce or depleting resources used). These issues are currently only blanket covered under the engineering parameter: 'harmful-side effects'

6. Conclusions

1. Existing TRIZ tools will be useful in Eco-innovation to solve technical or physical contradictions.

2. The TRIZ principles of 'ideality' and 'design without compromise' fit well in the philosophy of sustainable design.

3. It may be possible to extract 'principles' or 'operators' for solving environmental contradictions to support strategic environmental product management.

4. It would be beneficial if TRIZ provided a whole life-cycle perpective of the innovations it helps to create and covered more explicitally the environmental issues of hazardous substances, depleting resources and waste-recycling.

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