Lifecycle Assessment of the Environmental Benefits of Remanufactured Product within a "Green" Supply Chain

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Abstract - **The telecom industry is moving towards a "greener" supply chain for manufacturing. As part of this greening, more emphasis is being placed on logistics management, remanufacturing and recycling of e-waste. There has been much publicity concerning the environmental benefits of remanufacturing electronic equipment and reselling it to customers in lieu of manufacturing new like-kind equipment. This paper will provide an assessment of the environmental benefits associated with remanufacturing network telecommunications equipment by employing lifecycle assessment (LCA) methodology and commercially available LCA software / database information on these products. The results will demonstrate the significant environmental benefits of remanufacturing network telecommunications equipment as an "eco-sustainable" alternative to manufacturing new equipment.**

Index Terms— **Life Cycle Assessment, LCA, Remanufacture**

I. Introduction

Alcatel-Lucent is committed to reducing the impact of our products on the environment and to undertake initiatives to promote greater environmental responsibility through a variety of programs including creating a 'greener' supply chain. Within the company's operations is the Special Customer Operations (SCO) organization. The SCO organization started within the company in 1991 with the objective of supporting with remanufactured product a few legacy product lines manufactured discontinued but still requested by customers. Today, the organization has grown to handle many of the functions in the company that contain a reverse logistics component within the supply chain. These functions include the reverse logistics associated with the customer returned materials process, the recycling of old and obsolete products and remanufacturing. In addition, SCO has logistics responsibility in take-back programs required by legislation such as the European Union's (EU) Waste Electrical and Electronic Equipment (WEEE) directive. This directive requires electrical and electronic equipment waste to be collected and recovered, giving priority to reusing and recycling materials and products.

In 2008 the SCO organization remanufactured and sold more than 1,800 pieces of equipment (bays and panels) and 74,000 circuit packs totaling over 600 metric tons estimated weight of equipment thus keeping this out of landfills. Remanufacturing is the process of bringing a product to like-new condition through replacing and rebuilding component parts. Products that have been remanufactured have a quality that is equal to and sometimes superior to that of the new product. [1] The value to be recovered is significant and the estimate of total annual sales of remanufactured product is in excess of $50B in the United States alone. There are no worldwide estimates of the economic scope of remanufacture activities, but the number of firms engaged in remanufacturing activities is rapidly growing as increased profits provide strong incentives for firms to adopt remanufacturing as a business model. [2]

A robust reverse logistics process has been created in the company to facilitate the successful remanufacturing operation. In this regard, cost effect material acquisition streams have been identified to include the ability to pick-up, transport, and receive the material into inventory in a manner that compliments a remanufacturing strategy. The key to remanufacturing has been to keep costs low starting with acquisition and continuing through reverse logistic activities,

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inventory management, and the re-build processes. With this accomplished the strategy has been a tremendous financial value to the company as well as to the environment.

Remanufacturing offers a number of benefits to the company, including rapid order fulfillment due to on-hand inventory, lower cost \ higher operating profits \ increased market share, the ability to provide equipment needed by a customer that is manufactured discontinued as new , and the protection from third-party remanufactures and inexpensive "no-name" new competition. There are other substantial environmental benefits that include reduced new material content, energy, and the resulting greenhouse gas (GHG) emissions. Unfortunately these benefits are not documented for many items being remanufactured, including telecommunications equipment. The most common method to document, understand and disseminate the environmental benefits of remanufacturing is to conduct a Life Cycle Assessment (LCA) for the products. LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by compiling an inventory of relevant inputs and outputs of a system; evaluating the potential environment impacts associated with those inputs and outputs; and interpreting the results of the inventory and impact phases in relation to the objectives of the study. The study would require that LCAs be done on both the new and remanufactured versions of the product so the full environmental benefits from remanufacturing are captured.

Two LCA studies have been performed, one product from the company's wireline product portfolio and the other from the wireless. In 1997 the SCO remanufacturing scope expanded to include the remanufacturing and resale of company's 5ESS Switch switching product that includes wired equipment such as shelf units and cabinets assemblies. About the same time remanufacturing started of the company's wireless base transceiver station product line, the AMPS Autoplex Series 1. The paper [3] details the remanufacturing and business model for 5ESS and the model for the wireless product is substantially similar. This capability includes hardware remanufacture only. Software and services are not part of the remanufacturing model. Two LCA studies have been performed, one for the 5ESS multiplex AIU (Access Interface Unit) and one for the Modcell 4.0B. These remanufactured products are representative from the SCO wireline and wireless portfolios.

In each case the item studied is of a fully configured cabinet, with each cabinet being approximately 6 feet tall with contents that include units like the AIU, power converters, circuit cards, cooling fans, and signaling and power distribution cabling. Both of these products are considered to have long lifetimes after their remanufacture. In addition these items, or assemblies similar to them, are sold in quantities of hundreds through the course of a year. In each case the remanufacturing includes an upgrade. In the case of the AIU the upgrade was to the multiplex XAIU version. An AIU is a line access unit that is designed to serve all types of access lines including "POTS", "ISDN" and coin subscribers. In the case of the Modcell the upgrade was from the 4.0 to the 4.0B model. A Modcell is the company's name for a CDMA Base Transceiver Station (BTS).

There is much publicly claimed about the benefits of remanufacturing electronic equipment and reselling it in lieu of manufacturing new like-kind equipment. Remanufacturing is considered to be the highest form of waste prevention and environmentally conscious manufacturing. This analysis provides an in-depth quantitative assessment of the eco-impact benefits associated with remanufacturing telecommunications equipment. The analysis was performed by using a full lifecycle assessment methodology and the GaBi 4.0 PE International [4] LCA software / database information. The two products studied were specifically chosen because they are "real world" and do not represent hypothetical situations. For example, in the case of the XAIU, a quantity of twelve (12) of these were recently remanufactured for a service provider customer and this order was used as the model for inputs into that study.

II. SCOPE

A. Functional Unit

For the purposes of this LCA, a functional unit has been defined as the telecommunication services provided by the Modcell 4.0B and 5ESS multiplex AIU over the span of their typical lifetime of ten years. Given the considered lifetime of this equipment, there is no significant reliability difference between new and remanufactured products. Consequently, the maintenance requirements and use parameters will be the same for new and remanufactured equipment.

To compare the environmental benefits of a remanufactured product with a newly manufactured product, we need to consider the contributions to emissions from the manufacturing of the original product which has been recovered for remanufacturing. Consequently, the analysis contains two successive life cycles of a new product (i.e., two new products placed on the market) versus the life cycle of a recovered product that has been remanufactured (i.e., one new product replaced by a remanufactured product).

B. Theoretical Limit

For this case where one remanufacturing cycle is provided, the maximum theoretical reduction in environmental impact would be 50% (i.e. all elements of the telecommunications product is fully reused, and no additional refurbishing, testing, and transport is required for the product to initiate its reuse). This theoretical value would increase with each additional cycle of reuse of the new product – for two reuses the theoretical limit would be 66%; for three reuses it would be 75%; and for "n" reuses it would be 1/(1+n) x 100%. In practice, some level of refurbishment, testing, transport to and from the remanufacturing location is needed to allow the company to meet customers needs and also quality and warranty requirements. Additionally, some degree of hardware and software upgrades may occur to maximize the product's value to the customer. These factors lower the overall environmental impact savings associated with the remanufacturing. For network telecommunications equipment, the theoretical maximum would typically be 50%, which is associated with only one equipment reuse cycle, as the length of service life is quite long (10 to 15 years), making additional reuse cycles less likely.

C. System Boundries

The aim of the study is to compare new versus remanufactured products. To ensure a fair assessment, we will consider the full life cycle of the remanufactured product and compare:

- Two (2) successive life cycles of new products which are not reused at end of life (i.e., twice a new product life cycle), and
- The life cycle of a new product which has been recovered at the end of its first life, then remanufactured and reused.

TABLE I

Life cycle	Phase	New Product	Remanufactured product
First Life Cycle – New Products	Manufacture	M1	M2
	Use	U1	U2
	End-of-Life	E1	E2
Second Life Cycle – New or Remanufactured Products	Manufacture	M1	M3
	Use	U1	U3
	End-of-Life	E1	E3

Hence,
1) M1=M2: remanufacturing occurs only after the product has been used once; consequently, the new manufacturing phase is the same for the new product and the product to be remanufactured.
2) U1=U2=U3: as stated above, there is no difference in using a new and a remanufactured product, or 2 new products: the power consumption and maintenance requirements are expected to be equal
3) E1=E3: the end of life of a remanufactured product is expected to be the same as for a new product
4) E1≠E2: the "end of life" phase of a product to be remanufactured is specific as it will not be primarily recycled or land-filled, but reused
5) M1≠M3: M3 will be mainly reusing the existing product whereas M1 requires manufacturing and assembly of all product components.

Taking these into account and comparing the entire life cycles (M1 + U1 + E1 + M1 + U1 + E1 versus M2 + U2 + E2 + M3 + U3 + E3) can be simplified to E1+M1 versus E2+M3. Therefore for the purposes of this study the use phase, which was shown in other studies of telecommunication equipment to be the highest contribution to the different environmental impact categories, was excluded from the LCA.

D. Assessment Objects / Product Configurationst

Since this evaluation focuses on the differences between newly manufactured and remanufactured products, product configurations for both the 5ESS XAIU and Modcell 4.0B were selected that are similar to products that have actually undergone the remanufacturing process.

Tables II and III summarize the major assets that are included in the configurations. Figures 1 through 3 are photographs of a cabinet filled with XAIU units and circuit packs. The assets in Table II can be seen in the figures. Figure 1 is a front view of the cabinet showing three XAIU units that are filled with circuit packs. Figure 2 is a rear view of the cabinet with the three rear mounted XAIU units removed. In this figure additional assets listed in Table II such as the modular fuse filter unit in the top and cable wiring harnesses can be seen. The cooling fan is located in the bottom of the cabinet. Figure 3 is a photograph of the LPZ100 type circuit pack that is equipped in large quantities in the cabinet assembly.

TABLE II - 5E XAIU ASSETS

Asset	Quantity
Frame & Cabinet	1
Modular Fuse Filter Unit (MFFU)	1
Front Shelf Assembly	3
Rear Shelf Assembly	3
3-Fan Unit or 6-Fan Unit	1
Circuit Packs -- standard surface mount (SM) and through-hole (TH) components LPZ100 COMDAC PDXU	 112 12 1
Ring generator pack (RPG100), with non-standard heavy power components	4
Wiring Harness & Cables	5

TABLE III - MODCELL 4.0B ASSETS

Asset	Quantity
Pre-equipped Cabinet including shelfs	1
Filter Unit	3
Amplifier Unit	6
Digital Shelf Unit containing different Circuit Packs -- standard surface mount (SM) and through-hole (TH) components	12
Cabling	4

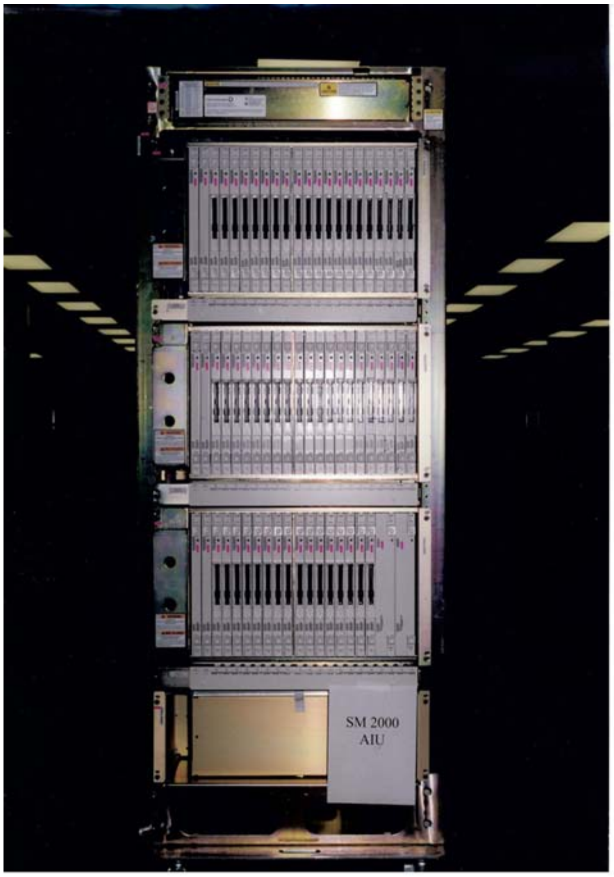

FIGURE 1 – Cabinet Front View

FIGURE 2 – Cabinet Rear View

FIGURE 3 – LPZ100 Type Circuit Pack

The Alcatel-Lucent LCA methodology is consistent with the ISO 14040 LCA series of standards (i.e., ISO 14040:2006, ISO 14044:2006) [5, 6].

For the physical inventory phase weights and material composition of mechanical and electrical parts were taken from earlier studies. Electronic parts such as the printed wire boards were analyzed on the base of their Bill of Materials (BoM) where all the parts and components contributing significantly to the total environmental impact are taken into account, particularly the printed wired board and the large ICs.

The impact assessment was performed with the GaBi 4.0 LCA tool using the data collected during the inventory and mapping the data with the items provided in the GaBi "Professional" and "Electronics" databases. For each major asset a GaBi plan was generated using specific processes (i.e., circuit pack or fan unit manufacturing) with inputs / resources (i.e., electronic components) and output flows, such as the emissions leaving the process (i.e., GHG emissions).

Then, according to the specified system boundaries (see above), in a first overview assessment of the Global Warming Potential of both products, the following life cycle phases were considered using the GaBi balancing tool section: manufacturing (including the transport to the assembling site) and the end-of-life phase (for example, metal recycling or plastic incineration). TABLES IV and V summarize these results.

Additionally, for the manufacturing phase of each product the different environmental impact factors were calculated. Of these calculated "environmental quantities", the normalized CML2001 – Dec. 07categories and the EDIP 1997 [7] category of fresh water consumption were selected for this comparison study. TABLES VI and VII summarize these "environmental quantities."

TABLE IV - GWP of Manufacturing and End-of-life of 5ESS multiplex AIU [kg CO2eq]

	New [M1+M1+E1+E1]			Remanufactured [M1+M3+E1+E3]		
Asset	Trans.	Manuf.	EOL	Trans.	Manuf.	EOL
Frame & Cabinet	27	694	119	27	371	60
Modular Fuse Filter Unit (MFFU)	52	64	16	27	32	8
Front Shelf Assembly	70	280	15	40	140	8
Rear Shelf Assembly	70	298	16	41	149	8
Fan Unit	36	270	11	36	270	11
Circuit Packs -- standard surface mount (SM) and through-hole (TH) components						
LPZ100	1646	12790	266	835	6395	133
COMDAC	164	1351	27	164	1351	27
PDXU	5	86	15	5	86	15
Ring generator pack (RPG100), with non-standard heavy power components	120	122		61	61	
Wiring Harness & Cables	2	50	1	2	33	0.5
Total GWP [kg CO_{2eq}]	2192	16005	486	1238	8888	270.5

TABLE V – GWP of Manufacturing and End-of-life of Modcell 4.0B [kg CO2eq]

	New [M1+M1+E1+E1]			Remanufactured [M1+M3+E1+E3]		
Asset	Trans.	Manuf.	EOL	Trans.	Manuf.	EOL
Pre-equipped Cabinet including shelfs	25	495	143	25	247	72
Filter Unit	6	1051	35	6	876	29
Amplifier Unit	198	1297	41	198	865	27
Digital Shelf Unit containing different Circuit Packs -- standard surface mount (SM) and through-hole (TH) components	423	2878	38	253	1977	21
Cabling	2	67	13	2	65	13
Total GWP [kg CO_{2eq}]	654	5788	270	484	4030	162

Assumptions for modelling the transport phase:

Electronic parts are shipped from Asia to NA [80% by way (a) 800 km in Asia, Airplane 12000 km from Asia to NA, Truck 1500 km in NA and 20% by way (b) Truck 800 km in Asia, Boat 10000 km Asia to NA, Truck in NA 2500 km]; Metal parts are transported by truck 2000 km in NA. For Remanufacturing only 2000 km truck transport from customer's site to SCO in NA is assumed.

III. INTERPRETATION

The values for the Global Warming Potential (GWP, kg CO_{2eq}) calculated through the first LCA for both products, the 5ESS multipleX AIU and the Modcell 4.0B, show a significant reduction by remanufacturing versus newly manufactured telecom equipment (Tables IV and V). For the switching product, savings of 44%, and for the base station, savings of 30% can be gained by remanufacturing compared to new manufacturing. The largest contribution to the emission of CO_{2eq} comes from the electronic parts, such as the printed wired boards; so, the higher the amount of reusable parts, such as the LPZ100 boards as in the 5ESS product, the higher the reduction of GWP factors.

TABLE VI - Comparison of different EI categories of new and Remanufacturing of 5ESS multiplex AIU

Environmental Impact Category (CML2001-Dec.07)	Unit	New Manufacturing M1	Re-manufacturing M3	Comparison: M1+M3 vs. 2*M1 =GWP Reduction by SCO
Abiotic Depletion (ADP)	[kg Sb-Equiv.]	38	4	44%
Acidification Potential (AP)	[kg SO2-Equiv.]	53	6	44%
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	3	0.4	44%
Freshwater Aquatic Ecotoxicity Potential (FAETP inf.)	[kg DCB-Equiv.]	57	8	43%
Global Warming Potential (GWP 100 years)	[kg CO2-Equiv.]	7662	905	44%
Human Toxicity Potential (HTP inf.)	[kg DCB-Equiv.]	2854	360	44%
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	[kg DCB-Equiv.]	3301763	630283	40%
Ozone Layer Depletion Potential (ODP, steady state)	[kg R11-Equiv.]	0.0008	0.0001	46%
Photochemical Ozone Creation Potential (POCP)	[kg Ethene-Equiv.]	3	0.4	44%
Terrestric Ecotoxicity Potential (TETP inf.)	[kg DCB-Equiv.]	20	3	43%
Water (fresh)	[kg]	85861	9081	45%

TABLE VII - Comparison of different EI categories of new and Remanufacturing of Modcell 4.0B

Environmental Impact Category (CML2001-Dec.07)	Unit	New Manufacturing M1	Re-manufacturing M3	Comparison: M1+M3 vs. 2*M1 =GWP Reduction by SCO
Abiotic Depletion (ADP)	[kg Sb-Equiv.]	14	6	31%
Acidification Potential (AP)	[kg SO2-Equiv.]	21	8	30%
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	1	0.4	31%
Freshwater Aquatic Ecotoxicity Potential (FAETP inf.)	[kg DCB-Equiv.]	19	8	29%
Global Warming Potential (GWP 100 years)	[kg CO2-Equiv.]	2887	1133	30%
Human Toxicity Potential (HTP inf.)	[kg DCB-Equiv.]	1282	495	31%
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	[kg DCB-Equiv.]	2120755	1090490	24%
Ozone Layer Depletion Potential (ODP, steady state)	[kg R11-Equiv.]	0.0002	0,0001	28%
Photochemical Ozone Creation Potential (POCP)	[kg Ethene-Equiv.]	1	0,6	30%
Terrestric Ecotoxicity Potential (TETP inf.)	[kg DCB-Equiv.]	9	4	30%
Water (fresh)	[kg]	19942	6777	33%

Looking at the different product life cycle phases for the newly manufactured, as well as the remanufactured assests, the results show that mechanical and electrical parts play a dominant role in contributing to environmental impacts over other life cycle phases, such as transportation of goods or end-of-life.

Additional environmental impact categories such as Acidification Potential, Human Toxicity Potential or fresh water consumption, which were assessed in a second LCA for the manufacturing phase of both products, confirmed the savings which can be obtained by remanufacturing of telecommunication goods (see Tables VI and VII).

IV. CONCLUSION

Telecommunication equipment remanufacturing offers Alcatel-Lucent significant benefits including reduced material and energy consumption that result in reduced environmental impact such as greenhouse gas emissions. To fully quantify the significance of these environmental benefits, the authors performed environmental impact lifecycle assessment (LCA) studies on two key products that customers are currently requesting in large demand – 5ESS multiplex AIU (Access Interface Unit) and the CDMA Modcell 4.0B (wireless base transceiver station). In order to provide valid results, the analysis was performed by LCA methodology that rigorously follows the ISO 14040 series standards for conducting environmental life cycle assessments. Modeling was performed using GaBi (4.3 version) LCA software with database information derived by PE International (makers of the software) and also from the ELCD (European Reference Life Cycle Data System) public database.

These modeling techniques and tools provided an effective means of comparing remanufactured telecommunications products with new manufactured products, including selected exchanges of legacy components with new components containing improved features and enhancements. For the remanufacturing cases studied, the Global Warming Potential (GWP) in terms of kilograms of carbon dioxide equivalents calculated for the remanufactured 5ESS XAIU and the Modcell 4.0B showed a reduction of 44% and 30% respectively, as compared to manufacturing a new product. The largest contribution to GWP comes from the printed wiring boards; so the greater the amount of reusable boards, the greater the resulting reduction of GWP. Additional environmental impact categories such as Acidification Potential, Human Toxicity Potential and Freshwater Consumption showed a similar percentage of reduction for these remanufactured products. Marine Aquatic Toxicity Potential showed slightly less savings (up to 20% less than the other categories).

Comparing these LCA results to the theoretical limits discussed earlier in this paper (50% reduction in GWP for one reuse of a product), the 5ESS AIU achieves 44% and the Modcell 4.0B achieves 30% reduction in GWP. Although these products compare favorably with the theoretical limits, the lower overall GWP reduction can be explained by the level of refurbishment (actual number of components reused or replaced including any hardware upgrades), level of testing associated with the products, transport distances and transport method (e.g., combination of truck, ship or airplane) to and from the remanufacturing location, and meeting customer requirements for quality and warranty.

The overall reduction in GWP for the two remanufactured products used for this LCA are not quite the same, but are consistent with what may be expected for these types of products. For example, the 5ESS AIU had a larger number of reused circuit pack assemblies than the Modcell 4.0B, and, therefore benefited from a reduction in the need for new circuit packs which are large contributors to GWP. Likewise, remanufacturing of the Modcell 4.0B requires a greater number of new components than the remanufacture of the 5ESS AIU, and , consequently a smaller reduction in GWP.

This paper has shown the environmental benefits of remanufacturing telecommunications equipment within a scope that compares the life cycle of one newly manufactured product and one remanufactured product to the life cycle of two newly manufactured products. This is appropriate since it allows that a product must be manufactured before it can be offered for remanufacture. However, it is significant to note that if the choice by a customer to purchase additional equipment was between a remanufactured (M3) product and a newly manufactured (M1) product (thereby negating the contribution from the first manufacture of the product), the overall reduction in GWP would double or increase to 88% for the 5ESS AIU and 60% for the Modcell 4.0B.

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