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Data Assessment and Collection for a Simplified LCA Tool

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Abstract

Life cycle assessment (LCA) is an essential practice for the Information and Communications Technologies (ICT) industry to use when developing products that use materials, manufacturing processes and energy resources more efficiently and drive towards being a sustainable entity. Additionally, stakeholders and public policy makers have begun setting expectations and requirements for LCA in the development of broad industry-based methodologies and standards. A major inhibitor in using LCA is the lack of sufficient and current environmental data for the processes and materials employed in the rapidly evolving high technology of ICT products. Furthermore, ICT products are composed of hundreds or even thousands of separate components from a multitude of suppliers. This can make the collection of environmental data and LCA-based information extremely complex.

The iNEMI (International Electronics Manufacturing Initiative) Eco-Impact Evaluator for ICT Equipment Project is developing a workable simplified design tool that could be used to more efficiently evaluate and produce environmental impact information for ICT products. A key part of this project is the assessment of data needs for use in the development of a simplified LCA-based tool for the ICT industry.

This paper provides an overview of the development of this simplified tool and the mechanisms for prioritizing and collecting pertinent data for the tool. Information will also be presented on the evaluation of possible mechanisms for providing efficient data collection from key suppliers to fill current data gaps and also provide a future mechanism for data refresh and updates.

Introduction

Life cycle assessment (LCA) is becoming a fundamental methodology within a broader sustainability management structure for businesses to use materials, manufacturing processes and energy resources more efficiently. LCA is typically evaluated over four main stages of a product's existence – manufacturing, transport, usage, and end-of-life treatment. LCA can provide substantive results when used within its limitations but it is resource intensive and challenging to apply properly. This is especially true in the information and communication technology (ICT) industry sector where the products are complex and technology evolves rapidly.

The International Electronics Manufacturing Initiative (iNEMI) set an objective to develop a methodology framework and estimation tool that could be used to more efficiently assess an ICT product's impact on human health and the environment (eco-impact). In Phase 1 of this undertaking, iNEMI formed the Eco-impact Estimator Work Group (WG) to research and define a simplified methodology framework. This work was completed in September of 2010 with its findings presented at the CARE INNOVATION 2010 Conference[1]. In Phase 2, the WG initiated development of a tool based on this framework for more efficiently estimating such eco-impact information. A key part of this second phase is the assessment of data needs for use in the development of a simplified LCA-based tool for the ICT industry. This document provides an overview of the development of this simplified tool and the mechanisms for prioritizing and collecting pertinent data for the tool.

1. Objective

The objective for the simplified LCA estimator is to provide a "proof-of-concept" tool based on the methodology framework that was previously developed. The estimator is intended to more easily estimate the eco-impact for different types of ICT hardware and equipment. It should provide sufficient accuracy to meet the LCA practitioner's intended needs in assessing the significant eco-impacts of a particular product type over its life cycle stages. A secondary objective for the WG was to develop mechanisms for prioritizing and collecting pertinent data for the tool from the supply chain. This latter objective is vital to the tool's capabilities, since adequate data from the ICT supply chain must stay abreast of the rapid technological advancements within the ICT industry in order for the estimator tool to be useful to the LCA practitioner.

2. Existing LCA Databases

In support of existing LCA methodologies[2] and standards[3], there are a number of life cycle impact assessment (LCIA) systems, databases and tools available. They offer varying degrees of information, global / regional data, industry processes, materials and flows, and mechanisms for more easily quantifying product eco-impacts. Currently available LCA software tools offer distinct but somewhat different capabilities for conducting eco-impact assessments for ICT products. The drawback is that these tools require a high level of LCA expertise and modeling experience and considerable effort to develop and collect the input data necessary to perform the assessment. Moreover, an analysis of published LCA results for consumer electronics has pointed out inconsistencies due to database differences, subjective choices, and difficulties of benchmarking due to non-transparent reporting[4].

In an effort to reduce the extensive resources needed in performing a full LCA on an ICT product, simplified LCA-based tools can offer an easier approach to quantifying eco-impact. They can also be simplified further to assess just a few key eco-impacts associated with ICT products such as global warming potential and freshwater usage for the manufacturing and use stages.

Another challenge for the ICT industry is in selecting existing databases that can provide global value, while allowing that data to be corroborated with current information from the ICT sector. Periodic updates are necessary to assure that the databases remain valid. Finally, the databases should be made publicly available and not include any proprietary information, such that it can be open to external peer review and continual improvement.

Because global warming potential is one of the most commonly evaluated eco-impact indicators, the WG decided to start with developing the LCA estimator tool that can estimate this particular eco-impact.

3. LCA Estimator Methodology Framework - Basics

The scope included the total life cycle, or from resource extraction through to end-of-life treatment. The estimator is designed to be capable of evaluating a product unit consisting of individual hardware equipment pieces. The product unit is attributed to a functional unit as defined by the product manufacturer. The functional unit is defined as a specified unit of end-use capacity or to deliver a certain type of end-use value or service over a given time period.

The system boundary typically defines which processes (on-site, upstream, and downstream) belong to the product system as defined in the functional unit. It also addresses the boundary between the technosphere and the ecosphere, i.e., the way the exchanges with nature are defined in a systematic way. Setting the system boundary means deciding which activities to include and which to omit for the different stages of the LCA. As a rule, all relevant activities must be included. Omission of certain processes can only be justified if they are insignificant to the outcome of the LCA study. The meaning of “insignificant” is determined from the intended application of the results and through explicit, quantitative cut-off criteria.

The LCA estimator tool employs the following steps:

- Define the goal and scope of the study, including defining the functional unit and system boundaries.
- Break down the ICT product into a structure that describes how the different parts fit together, and identify the component list.
- Set the base flow for the functional unit, e.g., one ICT product that operates over a given lifetime.
- Group the component list according to common ICT component categories.
- Populate the data for the assembly of the ICT product.
- Determine the transportation distances for the ICT product assembly nodes to the distribution center nodes, and then to the end-user locations.
- Determine the energy consumed during the “use stage” of the ICT product’s service life.
- Determine the probable distribution of end-of-life treatment for the ICT product. Use the approximate material composition for the ICT product as the input for the end-of-life stage.
- Calculate the eco- impacts using the LCA estimator tool.
- Evaluate the LCA estimator tool results and perform a sensitivity analysis on the results to confirm its validity.

4. Classification and Categorization of ICT Products

ICT products can be classified into distinct categories with common attributes that produce certain levels of eco-impact regarding their component makeup, assembly, usage, and design life. Upon analysis, these major classification categories are as follows.

- LAN (local area network) and Enterprise Telecom
- Service Provider Telecom
- PCs (personal computers)
- Printers
- Monitors
- Handheld ICT Devices

These classifications were then sorted into component categories comprised of similar materials and manufacturing processes. The components were then analyzed with regard to their respective contributions to the eco-impacts associated with raw materials extraction and processing, intermediate materials manufacturing, and component / subassembly manufacturing. The intent of categorizing these ICT components was to have a concise list that can be analyzed for common eco-impacting attributes, which can then be rationalized and modeled to derive their level of eco-impact within an LCA estimator tool.

Table 1 provides the major component / subassembly categories that the WG defined for ICT products.

Table 1: Categorization of ICT Products for Eco-impact Assessment

General Component Groups
Printed Wiring Boards (PWBs)
Integrated Circuits (including semiconductor devices)
Electro–Mechanical Components (fans, motors, etc.)
Metals / Metallic Mechanical Components (as found in cabinets, frames, structural parts, heat sinks, etc.)
Polymeric Mechanical Components (plastic parts)
Displays (electronic display devices)
Power Supplies
Large Capacitors
Batteries
Cables (signal, RF, power cords, wires, optical fiber)
Specialized Component Groups
Optical / Opto-electronic Devices (laser amplifiers, etc.)

Radio Frequency Components (power amplifiers, antennas, waveguides, etc.)
Disk Drives
Camera Devices (CCDs, etc.)
Lamps
Crystals
Polarized Glass
Copier Components (photoreceptor drum, fuser, laser scanning unit, toner cartridge, printer head, ink cartridge

As mentioned previously only the first eco-impact category, Global Warming Potential – 100 years, as measured by greenhouse gas emissions in units of carbon dioxide equivalents (kg CO_2e), was included by the WG in the initial phase of development for the LCA estimator tool.

5. Modeling Manufacturing Stage Eco-impact using Common Component Characterization

Based on the selection of Global Warming Potential as the targeted eco-indicator for this study, the LCA "Manufacturing" Stage of ICT Products can be modeled as follows.

The key parameters and metrics for assessing the eco-impact of components that comprise ICT products can be summarized for each of the categories listed in Table 1. Such parameters can represent the significant eco-impact contributors (per the defined boundary conditions and cut-off criteria) based on the analyzed datasets – internally available from within the ICT industry (e.g., integrated circuits) and externally available from other industry sectors (e.g., bulk metals and plastics).

An associated algorithm can be determined based on the LCIA data available for the above parameters. For example, a linear regression equation of the following type can be prepared for the component category of printed circuit boards[5].

$$\mathbf{GWP_{PWB} = A_B\ [\alpha + (\beta\ S_F) + (\gamma\ B_L)]}$$

Where: GWP_{PWB} is the total Global Warming Potential (100 years) for the printed wiring boards in the product / asset; expressed in kg CO2e

A_B is the area of the PWB; expressed in square meters

α is the "intercept" constant for this linear regression equation

β is the "PWB surface finish type" constant for this linear regression equation

S_F is the PWB surface finish type (e.g., HASL → $S_F = 1$; ENIG → $S_F = 2$)

γ is the "PWB layer" constant for this linear regression equation

B_L is the number of layers in the PWB

Life cycle impact assessment data is available from databases that exist worldwide. Nearly all of them have data on plastics and metals, which are important for the electromechanical and cabling portions that comprise electronic products. However in terms of electronics, a little over half of the databases surveyed have data surrounding electronic components.

The challenge for the ICT industry will be in developing and maintaining databases that can provide global value, while allowing that data to be corroborated with current information from the ICT sector. Updates will need to be made periodically to assure that the databases remain valid and that the functional units for the components and materials in the databases are accurately defined. Finally, the databases should be made publicly available and not include any proprietary information, so that they can be open to external peer review and continual improvement. The European Reference Life Cycle Database is a major step in this direction[6].

Detailed LCA analyses conducted on ICT products have shown that the component types providing the greatest contribution of environmental impact are the bare printed wiring boards (PWBs) and the large integrated circuits (ICs). Figure 1 shows the breakdown of the manufacturing stage CO_2 emissions for a network telecommunications product.

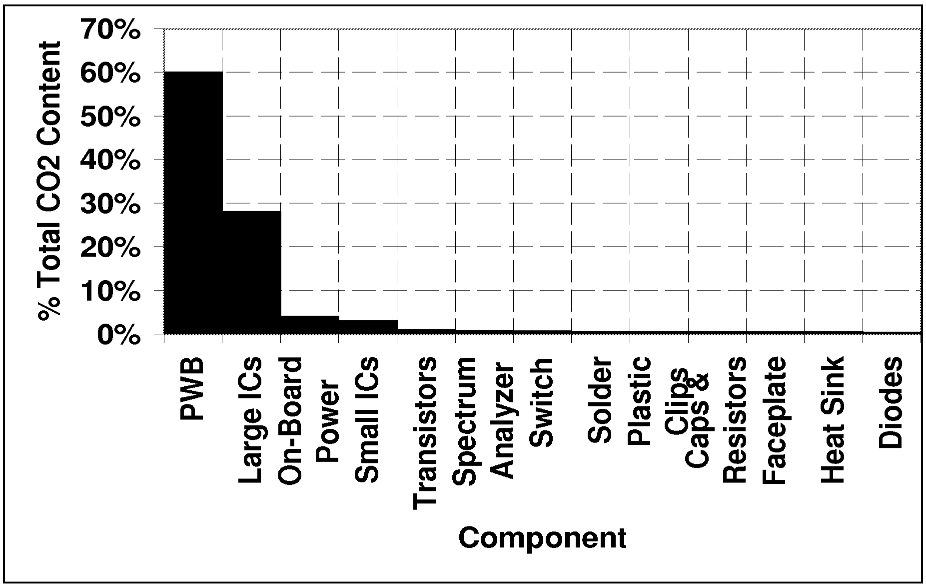

Figure 1: Percent CO2 contribution for each component type in a network telecommunications product

The bare printed wiring board (PWB), composed of the carbon bearing epoxy FR4, and the large integrated circuits such as plastic encapsulated Ball Grid Arrays (BGAs) together make up almost 90% of the manufacturing stage carbon content. Further investigation[5] of the PWB and of the large devices reveal other relevant facts. There is a linear functional dependence between the carbon content per unit area of a PWB and its number of layers – see Figure 2. Similarly for the large integrated circuits (ICs), the carbon content has a functional relationship with the number of pins. Algorithms derived from currently available data have been developed and incorporated into the LCA estimator proof-of-concept tool.

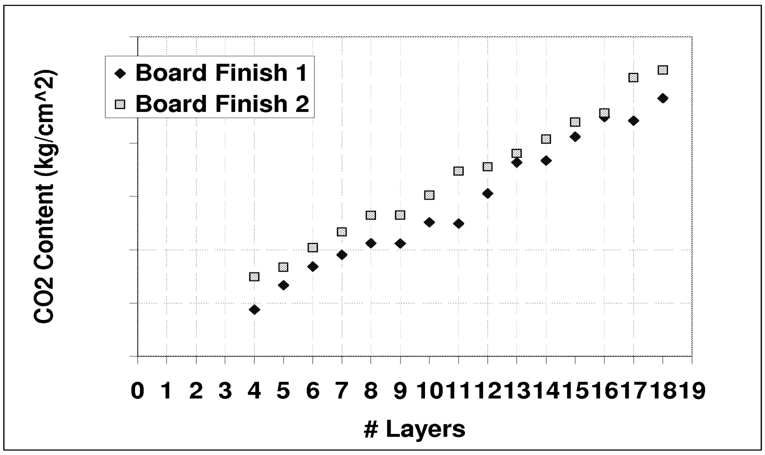

Figure 2: Plot of CO2 per unit area for boards with two types of finish

A key goal in developing the algorithms is that the end result should be within 15% of the result obtained from more complex methods for over 90% of the circuit pack assemblies investigated[7].

6. Modeling Manufacturing Stage Eco-impact using Equipment Parameterization

This approach[8] maps product characteristics to environmental impact through analysis of generic ICT products. This approach is based on previous work in streamlined LCA such as work done by Sousa et al. The approach aggregates comparable, relevant data with temporal and spatial uncertainty and variation. The goal of this probabilistic triage is to identify those key drivers of impact so that data collection can be focused on the aspects of a product life cycle "that matter" and thereby conserve limited resources for data collection. To accomplish this, the triage method relies on available data sources, but tries to accurately reflect the associated uncertainty that comes with the use of secondary data.

In summary the steps involved are:

1. High-level triage assessment based on available literature including uncertainty/variation. The significant research activity in this stage is quantifying the sources of uncertainty from grid mix variation, to supplier location and bill of materials weight ranges. From this high level, low-resolution assessment one performs statistical assessment that provides an understanding of the confidence in what drives global warming potential impact (driving down from life cycle stages to particular components with the product class of interest).

2. In conjunction with step 1, the LCA modeler identifies important candidate attributes of the product. These attributes include elements such as screen size, hard drive capacity, processor type. It is important to recognize that these attributes include ostensible (or knowable) attributes that can be determined by examining the product specifications, but also contextual attributes based on, for example, the location of product manufacture. Preliminary results have indicated that knowledge of only ostensible attributes does not provide sufficient resolution of product class impact.

3. These first two steps are used to refine targeted data collection using OEM data/feedback and supplier surveys where possible. These significant activities are mapped to attributes and then impact.

The modeling performed for equipment parameterization includes statistical contribution analysis to identify hotspots within the carbon footprint (see Figure 3). These are based on the most significant contributors to total impact. Quantitative metrics are provided to understand the significance of each phase or module’s contribution to impact.
This is then followed by statistical regression analysis to map to attributes to activities and impact. These regressions are based on existing data found in literature, industry data and disassembly data.

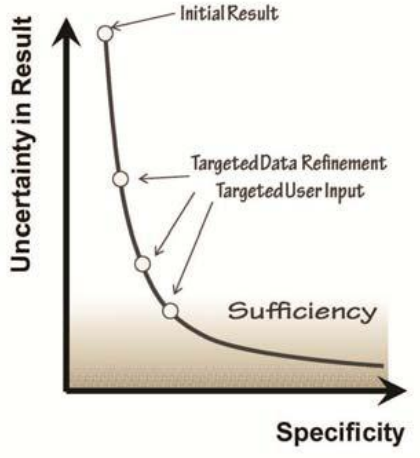

Figure 3: Targeting data and input around hotspots efficiently reduces uncertainty of result

Based on elements of the analysis, which at this point are at the product class level only, the modeler determines the desired resolution between product classes. The quantitative metric for this analysis is the “false signal rate” or the percent of the time chosen for the environmentally non-preferable product based on the variation in the results. For example, a 13” LCD screen produced in a facility without extensive abatement equipment will have a higher impact than a 14” LCD screen produced in a facility with extensive abatement equipment. False signal rate calculations then drive further resolution; based on the most significant contributors to variation between items the modeler would like to discriminate (e.g. activities, classes of product). For these analyses Sobol and Spearman coefficients are determined and activities are resolved to the extent possible until the desired false signal rate can be achieved.

7. Summing the Eco-impact for the LCA - Manufacturing Stage

For the manufacturing stage the LCA eco-impacts reflect the total of the ICT components' manufacturing, transport of components and intermediate materials to final product manufacturing locations, product assembly & testing, and product packaging. Transport of the intermediate materials, components, and subassemblies from their respective manufacturing facilities to the manufacturing facilities for final assembly into finished products includes discrete shipments from a large number of nodes (facilities) to one or more final assembly nodes. Typically, weight of the shipment and distance between the manufacturing nodes are included. Because the intermediates are very low in weight and shipped in bulk, the summation of the total transport venues was treated as an overall factor (typically less than 5%) applied to the total eco-impact of the product for this LCA stage[9].

The eco-impact for final product packaging was based on the packaging types used to ship the finished products to its intended distribution facilities and end-use locations. Packaging of intermediate components and materials was excluded in this estimation, as these items are typically packaged in bulk amounts, and the packaging materials can be considered to contribute an insignificant amount to the total LCA manufacturing stage.

Assembly and testing of the intermediate materials, components, and subassemblies into finished products and assets included processes such as surface mounting technology, thru-hole mounting technology, mounting of ICT product / asset, surface treatment (e.g., painting) for pre-manufactured cabinets, and testing of the ICT product. These parameters were treated as a collective summation of the total assembly and testing processes, and defined as an overall factor (typically less than 10%) applied to the total eco-impact of the product for the manufacturing LCA stage[9].

8. Modeling Eco-Impact for the "Transport" Stage

The parameters for assessing eco-impact of the logistics: transport, distribution and installation of ICT products / assets LCA stage were modeled as listed in Table 2.

Table 2: ICT "Transport" Stage Parameters and Metrics

Parameter	Metric
Location of final product assembly / EMS	Nodal point – by region
Location of product integration center / warehouse	Nodal point – by region
Location of final product installation	Nodal point – by region
Transport mode	Selection of modal mix) – e.g., surface mix (truck, rail, marine vessel), air transport (plane), etc.
Transport mode GWP factors	kg CO2e per kg of shipped product weight per km traveled – e.g., air travel, marine travel, truck travel, rail travel. Additional factors to be considered include: ▪ Transportation equipment used (e.g., heavy gross weight transport vehicle) ▪ Fuels used (e.g., diesel from petroleum refinery) ▪ Load factor of the means of transport used ▪ Empty return rate of the means of transport used
Final product shipping weight	kg.

The total eco-impact associated with the installation of an ICT product is highly dependent on its type. For small ICT devices that are designed for consumer premises (e.g., PCs, printers, IP phones, cable modems), few – if any, ancillary materials, parts, and resources are needed to complete the installation such that the eco-impact from installation can be considered negligible to the total eco-impact of the Transport LCA Stage.

On the other hand, for network servers and telecom products the ancillary materials, parts, and resources necessary to

complete an installation at a customer's premises may be more significant. Typically an assessment of these materials and resources would be needed to further determine the eco-impact related to the specific installation.
For the Transport LCA Stage the summation of eco-impacts then included these above-mentioned parameters.

9. Modeling Eco-Impact for the "Use" Stage

The parameters for assessing eco-impact of the use of ICT products can be modeled as listed in Table 3.

Table 3 – ICT "Use" Stage Parameters and Metrics

Parameter	Metric
Location where product is used	By region or country
Power consumption - per typical product configuration and feature set	Kilowatts (kW)
Power usage per annum	Kilowatt-hours per year
Product operating life	Time period product is expected to be used (e.g., design operating life, in years)

The power consumption of the product should be based on its typical configuration and feature set deployed. This should also include the power needed to cool the equipment internally, e.g., fans and heat exchangers within an equipment cabinet or enclosure. For external cooling necessary to transfer heat, control humidity levels, and cool the surrounding equipment area, e.g., CRAC unit within a central telecom office / server facility, there should be an apportionment of the energy needed to maintain typical temperature and humidity requirements of the equipment being assessed for the region it is deployed.

For power usage per annum, this can be an average daily power usage based on a typical pattern of usage that includes sleep modes and other power saving features. A use profile can be estimated or derived from studies on actual product usage by end users. Some governmental agencies have developed such use profiles for certain ICT product categories, e.g., US EPA Energy Star Program[10].

The product operating life can be its design life – typically in years. Design life is usually determined by the product's reliability factors, i.e., the point at which product failures are expected to increase above a prescribed level of acceptance as defined by the manufacturer for the end user.

The eco-impact associated with servicing of the ICT product is highly dependent on its type. For small ICT devices that are designed for consumer premises (e.g., PCs, printers, IP phones, cable modems), and having a relatively short operating design life, servicing resources are typically small such that the eco-impact from such servicing can be considered insignificant to the total eco-impact of the Use LCA Stage.

On the other hand, for network servers and telecom products that may be in operation for a longer lifetime, servicing with consumable parts, materials and resources may be more significant. In such cases an assessment of these parameters may be needed to further determine the eco-impact. For simplicity, factors may possibly be developed and applied within the algorithm for the Use LCA Stage.

10. Modeling Eco-Impact for the "End-Of-Life" Stage

The parameters for assessing eco-impact of the end-of-life of ICT products can be modeled as listed in Table 4.

Table 4 – ICT "End-of-Life" Stage Parameters and Metrics

Parameter	Metric
Product constituent materials - weight	Weight (kg) of constituent materials, e.g., circuit boards, frames / chassis, metals, polymers, etc.

Disposition of product constituent materials - percentage	Percentage (%) of constituent materials receiving end-of-life treatment, e.g., full recycling, incineration / energy recovery, landfill disposal

The parameters presented in this table can provide a simplistic means of evaluating the End-of-life LCA Stage. Key to this is the factors that represent the eco-impacts associated with these different treatment schemes. Proper (environment-conscious) end-of-life treatment was only considered in this analysis for the estimator tool. Typically such treatment is provided locally (within region), so transport to such treatment, recycling and final disposition facilities can be included within factors developed for this LCA stage. There can be more sophisticated approaches taken to develop end-of-life treatment models (e.g., European Life Cycle Data System[5]). However, in the experience of the iNEMI WG the eco-impacts of the End-of-life LCA Stage are rather small relative to the overall LCA, and thus may not warrant such sophisticated treatment.

11. Constructing the LCA Estimator Tool

Based on the previously presented modeling analyses for the four major LCA stages of an ICT product, a proof-of-concept LCA estimator tool can be developed. The iNEMI WG is currently in the development and test phase of the tool with an expected completion of April 2012. Figure 4 displays the summary worksheet.

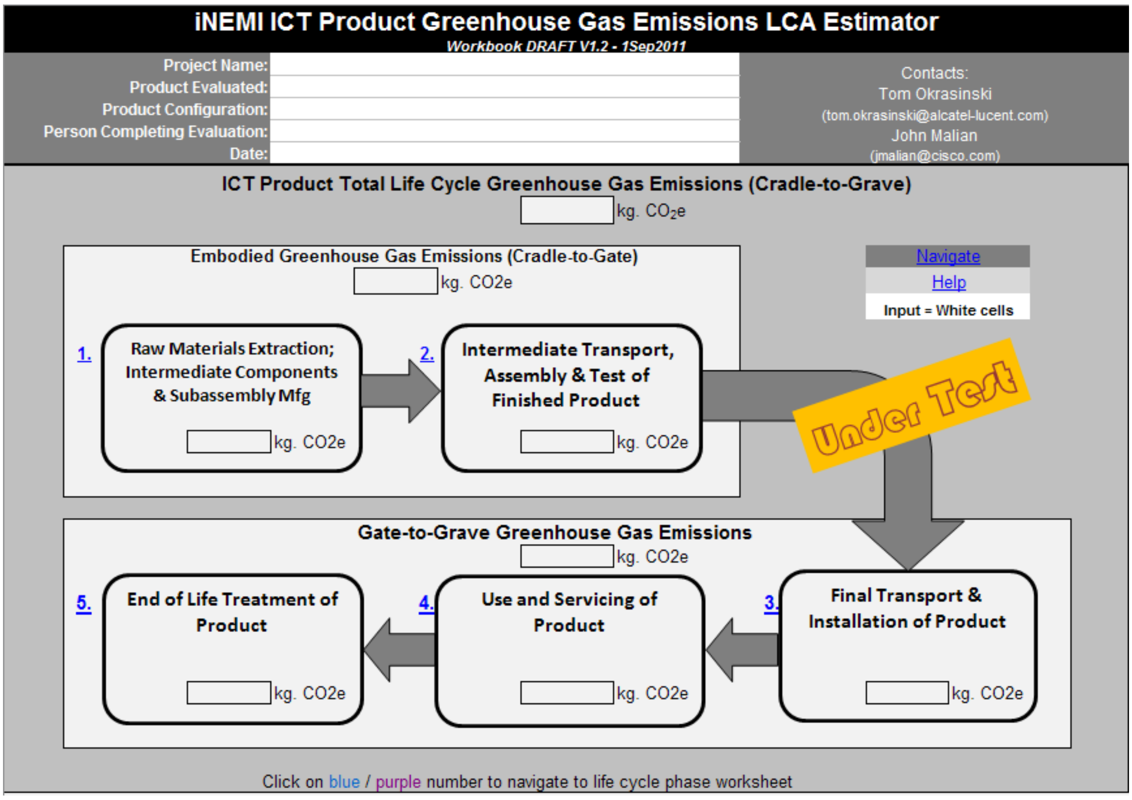

Figure 4: LCA Estimator Tool – Cradle-to-Grave Eco-impact Summary Worksheet

Each of the modules in the summary worksheet have supporting worksheets that provide additional entry input for bare PWBs, large ICs and other component categories. Figure 4, Figure 6, and Figure 7 show the worksheets for the finished product transport stage; use stage; and, end-of life treatment stage, respectively.

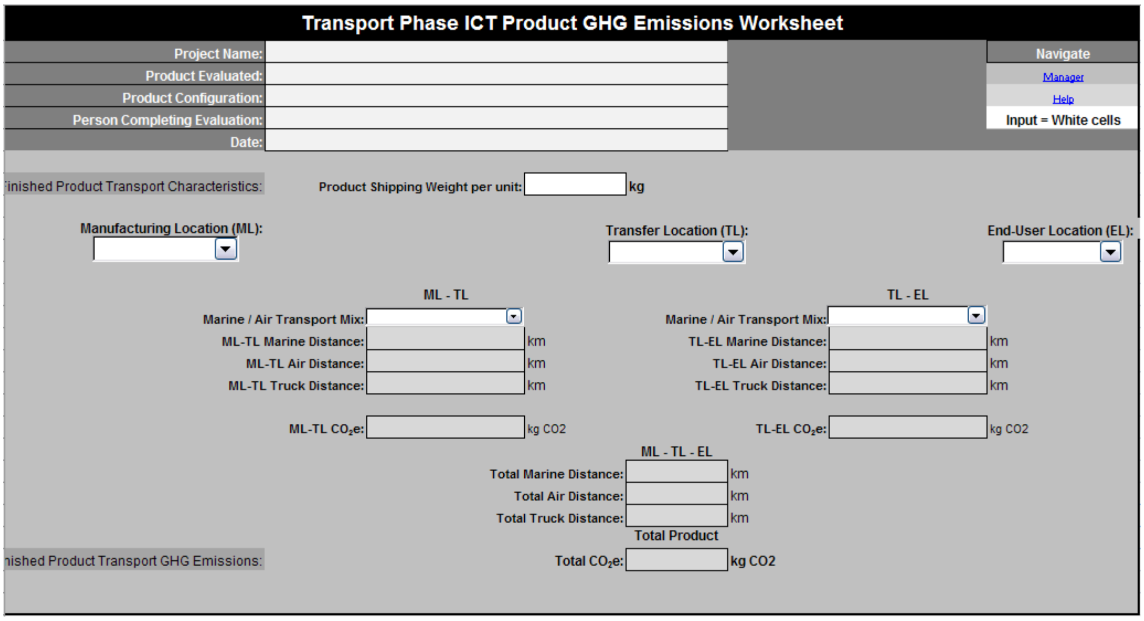

Figure 5: LCA Estimator Tool - Transport Stage Worksheet

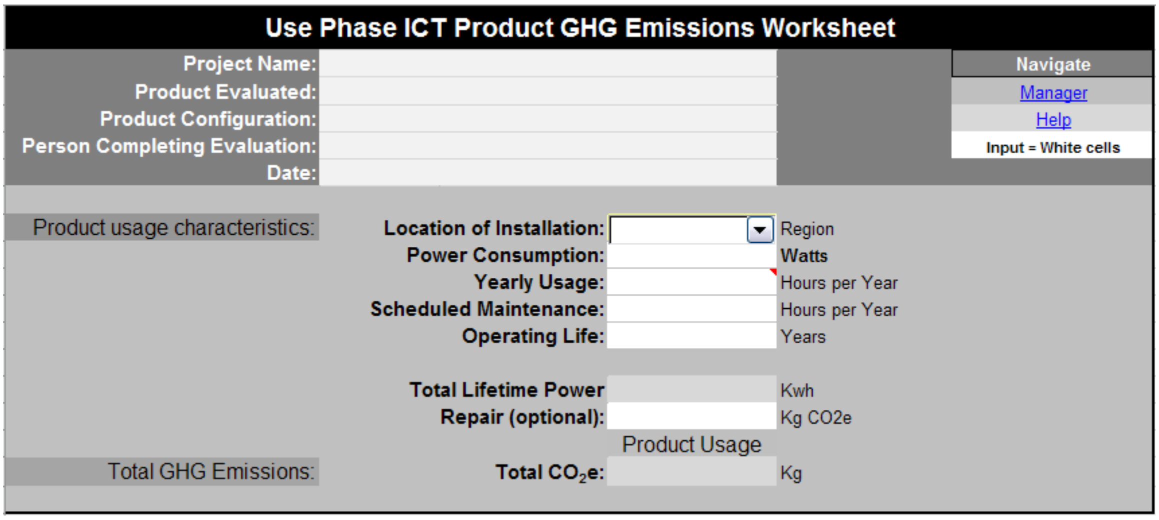

Figure 6: LCA Estimator Tool - Use Stage Worksheet

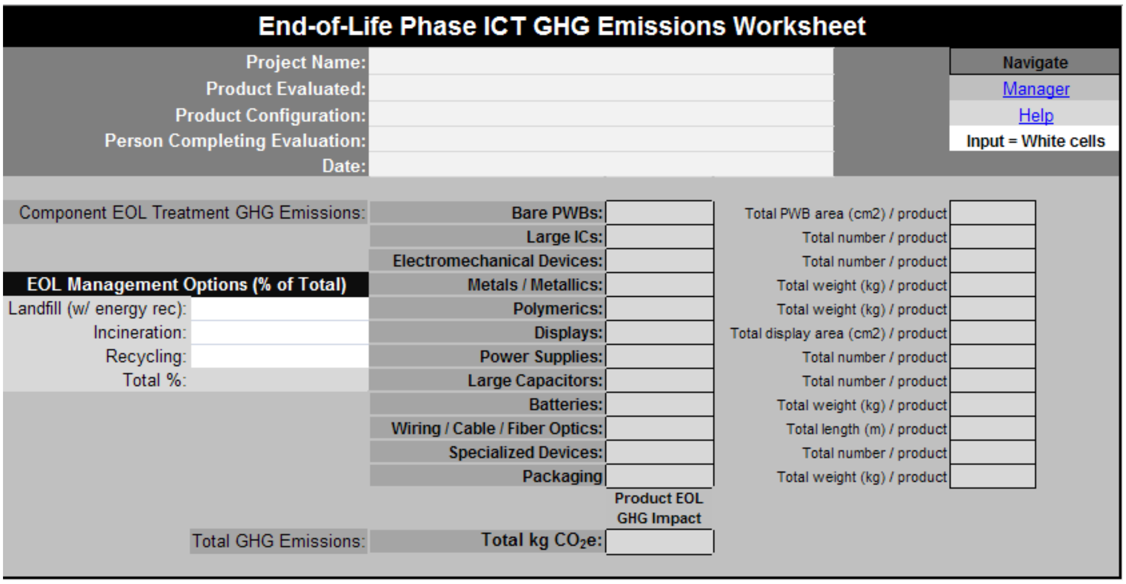

Figure 7: LCA Estimator Tool - End-of-Life Treatment Worksheet

Other aspects of the tool development include prototype testing, comparison of test results with known detailed LCA results (published and/or within the ICT industry), and development of data collection and maintenance guidelines. In addition, uncertainty studies will be performed to understand the level of uncertainty compared to LCAs that are performed using the commonly used tools in industry.

12. Conclusion

The LCA estimator proof-of-concept tool defined in this document can provide the basis upon which LCA practitioners can assess the greenhouse gas (GHG) emissions of ICT products over their full life cycle – manufacturing, transport, use, and end-of-life treatment. The available LCIA databases and information on the GHG emissions of ICT products and components referenced and collected by the WG provide a starting point for the development of algorithms that can be employed in the estimator tool.

Additional approaches for collecting and developing LCIA data has been presented in this document. They include the commonalities of ICT component classification as represented by linear functional dependence algorithms based on key parameters of a component class, e.g. the GHG emissions per unit area of a PWB and its number of layers; and the ICT equipment parameterization as represented by the probabilistic triage approach that uses key drivers that focus on the aspects of a product life cycle that matter. Algorithms derived from these approaches have been developed and can be incorporated into the LCA estimator proof-of-concept tool.

It is vital that the ICT industry collaborates on developing and collecting additional LCIA data and information for the different life cycle stages that are representative of ICT products. In the iNEMI Workgroup's experience as well as in external LCA studies, the "Use" stage of ICT products typically contributes the majority of eco-impact for the full LCA. This is followed then by the "Manufacturing" stage. Consequently, emphasis should be concentrated on providing more refined data and information for these two stages.

LCIA data improvement within the ICT industry must parallel the technological advances that are rapidly evolving within this industry. In order to effectively collect and incorporate this data into the LCA estimation tools presented in this document, LCIA the data assessment techniques mentioned above could provide an appropriate means to achieve the necessary end results.

13. References

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